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JUDGING AN AMPLIFIER BY MEANS OF THE TRANSIENT CHARACTERISTIC

by J. HAANTJES. 537.545

The properties of amplifiers can be judged on the basis of characteristics which represent the amplification of the amplitude and the shift in phase as functions of the frequency. The characteristic of the phase shift is usually left out of consideration since its meaning is not graphically expressed. In certain cases, however, the judgment of an amplifier by means of the amplitude characteristic alone leads to erroneous conclusions. The behaviour of the amplifier can then best be characterized by the so-called transient characteristic, which indicates the output signal for a discontinuous change of the input signal. In this article the amplitude characteristics and the transient characteristics are discussed for a number of common coupling networks of amplifiers. It is shown that the transient characteristic of an amplifier furnishes the same information as the amplitude and phase characteristics together. In conclusion the concept of transient characteristic is extended to high-frequency amplification where it is not a question of the entire variation of the input signal, but only of its modulation. The single sideband reception customary in television sets here leads to interesting complications which are discussed by means of a simple example.

The amplification of electrical signals is a very common problem in electrotechnology. By this amplification is meant the excitation of a voltage or current which, considered as a function of the time, gives a diagram which has the same shape but a larger amplitude than the original electrical signal.

A familiar example of the application of amplification of signals is seen in the cathode ray oscillograph. This instrument makes visible the variation with time of weak signals (for instance voltages of 1 mV), while the cathode ray tube requires a deflection voltage of about 10 V to produce a reasonable deviation. The first requirement of an amplifier which must convert the signal voltage of 1 mV into a deflection voltage of 10 V is undoubtedly that the variation with time of the deflection voltage should give a true picture of that of the signal voltage.

Another example is found in the amplifier of a radio or television receiver. The input signal of these sets is a high-frequency voltage, generally with varying amplitude. This variation of the amplitude, the so-called modulation, is the quantity to which the voltage or current generated must be proportional .The voltage or current generated when drawn as a function of the time, thus does not actually give a picture of the signal voltage itself but only of its modulation. We shall in this case also, however, speak of the amplification of the signal voltage, and we shall show that there is a far-reaching analogy between the two cases.

The object of obtaining an amplification which is accurate in shape is approximated more or less in practice, according to the circumstances, but never entirely achieved. The deviations from the desired result may be divided into two groups. The first group is formed by deformations which increase with increasing amplitude of the input signal and disappear for a sufficiently small amplitude of the input signal. In this case one speaks of distortion due to non-linear amplification. The second group of deformations is present even at an indefinitely small amplitude of the input signal, and may be ascribed to the fact that the amplified voltage at a certain instant is not given unambiguously by the magnitude of the signal voltage, but, for example, depends at the same time upon the derivative of the signal voltage with respect to time, or on an integral of the signal voltage over the time.

An important property of these deformations is

that they also occur in networks which only contain elements which satisfy Ohm's law, so that each branch may be characterized by a definite resistance or a definite complex impedance. Such networks are called linear networks, and the deformation is also called linear deformation.

In this article we shall examine the way in which the properties of an amplifier, especially with respect to its linear deformation, can most suitably be characterized. It will be shown that the well-known amplitude characteristic of an amplifier, which represents the amplitude of the input signal as a function of the frequency, is often unsuitable as a means of judging the properties of an amplifier. If a complete characterisation of the properties of an amplifier is desired, then, in addition to the amplitude characteristic, the phase characteristic must also be known. In this article, however, attention will be focussed upon an entirely different method of determining the properties of an amplifier, namely by means of a curve which indicates how the amplifier reacts to a single, discontinuous change in the signal voltage. This curve, which we shall call the transient characteristic of the amplifier, can be used to advantage in exactly those cases, where the amplitude characteristic alone does not give sufficient information. On the basis of a number of examples, we shall try to give a qualitative survey of the relation between amplitude characteristic and transient characteristic.

Fourier analysis and amplitude characteristic

Any signal $v(t)$ which is applied to the input of an amplifier can be approximately represented by a Fourier series with a number of frequencies ω_n:

$$v(t) = \sum_n a_n \cos(\omega_n t + \psi_n) \quad . \quad . \quad . \quad (1)$$

With a perfectly accurate amplification the output signal $V(t)$ would simply be a factor f larger than the input signal:

$$V(t) = \sum_n f a_n \cos(\omega_n t + \psi_n).$$

If, however, linear deformation is present, each frequency ω_n may be amplified by a different factor f_n, while in addition a phase shift φ_n will in general occur, so that the output signal may be written as follows:

$$V(t) = \sum_n f_n a_n \cos(\omega_n t + \psi_n - \varphi_n), \quad . \quad . \quad (2)$$

where f_n and φ_n are functions of the frequency ω_n, but not of the amplitude a_n. $f(\omega)$ and $\varphi(\omega)$ are called the amplitude and the phase characteristics respectively, of the amplifier [1]).

If for example it is assumed that the amplification factor τ is independent of the frequency ω and that moreover φ is proportional to ω, so that $\varphi_n/\omega_n =$ = constant = f, equation (2) can be converted into:

$$V(t) = f \sum_n a_n \cos(\omega_n t + \psi_n - \omega_n \tau) =$$
$$= f \sum_n a_n \cos\{\omega_n(t-\tau) + \psi_n\} = f \cdot v(t-\tau), \quad (3)$$

or, to the same effect,

$$V(t+\tau) = f \cdot v(t) \quad . \quad . \quad . \quad . \quad (4)$$

This means therefore that the output signal is exactly the same in shape as the input signal, and that it merely lags behind it by a time τ. Such a retardation is no objection for most applications, so that the fulfilment of the conditions that:

f is independent of ω, and
φ is proportional to ω

guarantees the satisfactory performance of the amplifier.

In practice indeed an attempt is usually made to give to amplifiers, which must amplify accurately as to form, the flattest possible amplitude characteristic; too little attention, however, is sometimes paid to the phase characteristic. This is understandable to some extent, when it is kept in mind that the phase behaviour in sound amplifiers, and therefore also in radio receivers, is of practically no importance. In order to make a natural impression on the ear it is unnecessary that the sound be reproduced faithfully. It is here only a question of the correct transmission of the frequency spectrum, and the phase relation between the different components is of little importance within wide limits. This is the reason why, in addition to the absence of non-linear distortion, the approximately flat shape of the amplitude characteristic is practically the only requirement which is here made.

In the case of oscillograph amplifiers and television amplifiers, on the other hand, a flat shape of the amplitude characteristic offers no guarantee

[1]) If in addition to linear deformation, non-linear deformation is also present, f and φ change not only with the frequency but also with the amplitude. Moreover, frequencies occur in the output signal which are not present in the input signal, so that, taken strictly, it is no longer possible to speak of an amplitude characteristic or a phase characteristic. On the subject of the characterization of non-linear distortion see for example Philips techn. Rev. 4, 354, 1939, equations (1) and (2).

[2]) See in this connection the article by J. F. Schouten, Philips techn. Rev. 4, 167, 1939.

of satisfactory performance. Let us consider for example a simple resistance amplifier, of which the connections are indicated in *fig. 1* ($R' \gg R$). When the valve capacities may be neglected so that the

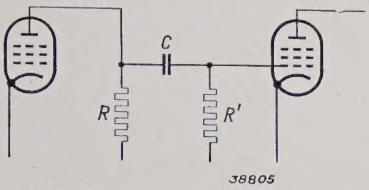


Fig. 1. Coupling between two valves of a resistance amplifier. The capacities between the electrodes of the valves are neglected in this diagram.

scheme indicated is exactly valid, the amplification factor will increase with increasing frequency and finally reach a limiting value for frequencies for which the impedance of the condenser C is small compared with R'. At these high frequencies a perfectly accurate amplification of the input is then obtained.

We now consider the reproduction of a block-shaped signal (*fig. 2a*) whose period is so short that already at the fundamental frequency 98 per cent of the maximum amplification is obtained. In this case one would be inclined to think that almost no deviation from the square form could any longer appear in the output signal. Actually, however, the variation of the output voltage obtained is that shown in fig. 2*b*, which differs very much from the block-shaped signal voltage. If the amplifier is part of an oscillograph apparatus, fig. 2*b* shows graphically the distortion of the oscillograms which must be expected.

On the basis of the amplitude characteristic of

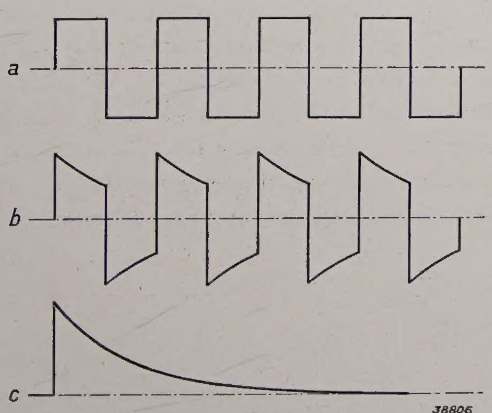


Fig. 2. a) Block-shaped input signal, by means of which the reproduction of an amplifier can be investigated. *b*) The output signal which a resistance amplifier according to fig. 1 gives with an input signal according to curve *a* when the frequency is chosen so low that the fundamental wave is attenuated by 2 per cent by the impedance of the coupling condenser. *c*) The output signal for an input signal which suddely jumps from 0 to 1 at $t = 0$ and then remains constant (transient characteristic).

the amplifier one would certainly not expect this distortion. If the phase characteristic is taken into account as well, this distortion can, however, be deduced, since amplitude characteristic and phase characteristic together give a complete picture of the behaviour of an amplifier in the absence of non-linear distortion.

Transient characteristics

As we have seen, the amplitude characteristic $f(\omega)$, which describes the reproduction of sinusoidal signals, does not furnish sufficient information about the fidelity with which a given signal is reproduced. The oscillogram of a block signal, fig. 2*b*, approaches this result much more closely, so that this oscillogram might be considered directly as a characteristic of the amplifier. This method can be still somewhat simplified by choosing as input signal instead of the series of discontinuous voltage changes of which the block signal is made up, a single discontinuous increase of the voltage, It was Heaviside who first investiged the behaviour of all kinds of electrical networks with such an input signal. The treatment of the mathematical problems thereby encountered led him to the development of operational calculus [3]). In this article, however, we shall work only with ordinary differential equations. In the case of the resistance amplifier dealt with above, upon a discontinuous increase in the input signal, the output voltage will also increase discontinuously and then decrease exponentially to zero. This "transient characteristic" of the resistance amplifier is reproduced in fig. 2*c*. From the slope of the exponential curve, which represents the variation of the output voltage for a constant input voltage, it is easy to estimate the distortion to be expected in a block signal of a given periodicity.

Examples of transient characteristics

Ordinary amplifiers are so constructed that they give a reasonably faithful reproduction for a given frequency range, while for higher as well as for lower frequencies distortions occur. The example, on the basis of which we developed the concept of transient characteristic, referred to the behaviour of amplifiers on the low-frequency side of that range. The most interesting problems occur, however, on the upper boundary of the frequency region of accurate reproduction. Repeatedly in this periodical the means have been discussed which can

[3]) A concise explanation of operational calculus and its application to discontinuous phenomena was given in this periodical by B. van der Pol and Th. J. Weyers, Philips techn. Rev. 1, 363, 1936.

be employed for the improvement of the accuracy of the amplification for signals with these high frequencies, not only in the case of the amplifier valves themselves but also in the networks for

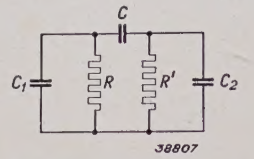


Fig. 3. Complete coupling network of a resistance amplifier. It contains the parasitic capacities C_1 and C_2 which result in a decrease in the amplification for high frequencies.

coupling the successive valves [4]). Since linear distortion originates mainly in the networks, we shall limit our considerations to them. If we again start with a resistance amplifier, an undistorted amplification can only be obtained when the anode impedance of the amplifier valve behaves as a pure resistance at all frequencies under consideration. In the scheme indicated in fig. 1 this would be true above a definite minimum frequency. Actually, however, besides the circuit elements indicated in fig. 1, there are always parasitic capacities present, namely capacities between the electrodes of the amplifier valves as well as between certain parts of the wiring and earth. If these capacities are taken into account the coupling network given in *fig. 3*, is obtained between two successive valves, and it is clear that now there can be no question of a constant anode impedance; the impedance decreases with increasing frequency as a result of the parasitic capacities C_1 and C_2.

Various connections have been devised in order to oppose the fall in impedance up to as high frequencies as possible. Four different examples of improved coupling networks are shown in *fig. 4* beside the simplest coupling network. The network *II* can for instance be derived from *I* by connecting a self induction in series with the anode resistance. An attempt is here made to compensate as far as possible the fall in the total anode impedance due to the capacities C_1 end C_2 by a corresponding increase in the impedance of L. If the fundamental shortcomings of this scheme are studied, the network *III* is reached as the first stage in its improvement, etc.

An important problem is now to ascertain to what extent these coupling networks used in oscillograph amplifiers and television amplifiers actually do produce better results than the simple resistance coupling. We shall study this problem on the basis of amplitude characteristics as well as on that of transient characteristics. For the sake of simplicity we shall neglect deformations by the amplifier valves and consider only the coupling networks. The input signal is then best chosen not as a certain voltage, but as a certain current which represents the anode current of the preceding amplifier valve. The output signal of the network is a certain voltage, namely the grid alternating voltage of the following valve. The calculation of the amplitude characteristics is based upon familiar principles and need not be described in detail here. There is a great diversity of possible results, since those circuit elements which are not expressly indicated by letters in fig. 4 may be chosen arbitrarily. If these elements are always chosen so that the amplitude characteristic is as flat as possible at low frequencies, then for the five networks indicated the amplitude characteristics represented in *fig. 5* are obtained. In this figure the ratio between output

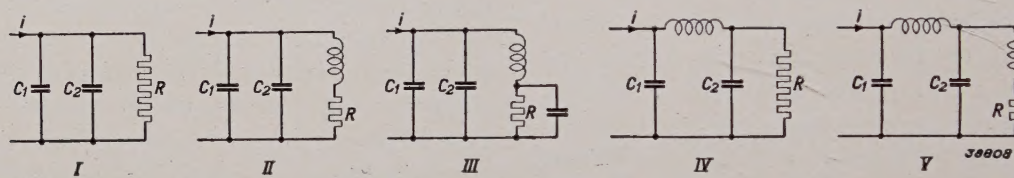


Fig. 4. Coupling network of fig. 3 and several improved coupling networks whose amplitude characteristics remain flat to higher frequencies.

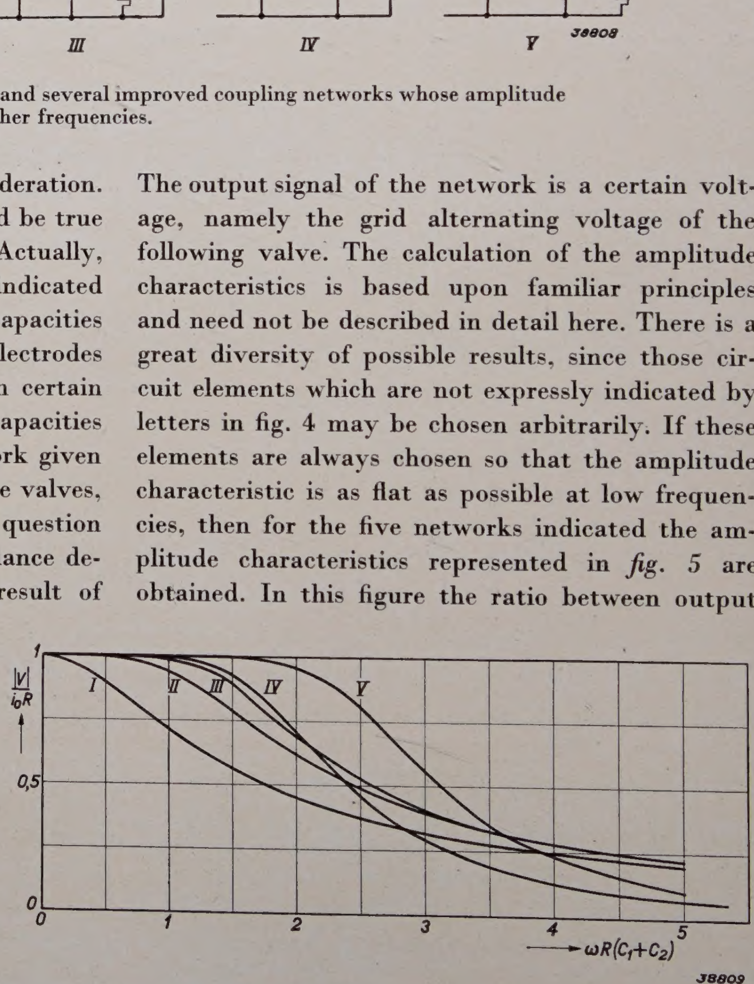


Fig. 5. Amplitude characteristics of the coupling networks shown in fig. 4.

[4]) Philips techn. Rev. 4, 342, 1939.

voltage and input current is plotted as a function of ωR $(C_1 + C_2)$, where the value of this ratio is set equal to unity for very low frequencies.

On the basis of the graphs of fig. 5, one is led to the conclusion that the accuracy of the amplification at high frequencies is very much improved by the elaboration of the coupling network. If, for example, a decrease in the amplitude to 90 percent of the maximum value is considered permissible, then the upper limiting frequency of network *II* is more than double that of the pure resistance coupling *I*, while the improvement in the network *V* even amounts to more than a factor 4. On the basis of experience gained with the amplitude characteristic at low frequencies, however, we know that it is still uncertain what is the significance of these results for the accurary of the amplification of any arbitrarily varying signal.

We shall now consider the transient characteristics of the same five coupling networks. At the moment $t = 0$ the input current jumps from $i = 0$ to $i = i_0$ and keeps this value. What is required for each network is the behaviour of the voltage on the capacity C_2. It is here always assumed that up to the moment $t = 0$ there is no electrical energy present in the circuit. The condensers thus have the charge zero and the self-inductions a zero current.

As an example, the calculation will be carried out in the following for the case of the network *II*. For this purpose it is necessary to choose a definite value for the selfinduction which occurs in these connections. In order to obtain the amplitude characteristic reproduced in fig. 5, curve *II*, this self-induction must possess a value $L = 0.414\, R^2(C_1 + C_2)$. If, further, we let $C_1 + C_2 = C$, the voltages and currents in the network satisfy the following equations:

$$\left.\begin{aligned} V = \int_{-\infty}^{t} \frac{i_C}{C}\, \mathrm{d}t &= L \frac{\mathrm{d}i_L}{\mathrm{d}t} + Ri_L, \\ i_0 &= i_C + i_L. \end{aligned}\right\} \quad \ldots \quad (5)$$

The voltage V is required as a function of the time. Elimination of i_L and i_C gives:

$$LC \frac{\mathrm{d}^2V}{\mathrm{d}t^2} + RC \frac{\mathrm{d}V}{\mathrm{d}t} + V - Ri_0 = 0.$$

If $V - Ri_0 = v$ then the following holds for v:

$$LC \frac{\mathrm{d}^2v}{\mathrm{d}t^2} + RC \frac{\mathrm{d}v}{\mathrm{d}t} + v = 0.$$

By substitution of $v = A\, e^{at}$ the so-called characteristic equation is found

$$a^2 + \frac{R}{L} a + \frac{1}{LC} = 0,$$

from which it follows that

$$a = -\frac{R}{2L} \pm \sqrt{\frac{R^2}{4L^2} - \frac{1}{LC}},$$

or, with the above indicated choice of $L = 0.414\, R^2C$:

$$a = -\frac{1{,}209}{RC} \pm j\frac{0{,}980}{RC}.$$

The general solution is therefore

$$v = Ae^{-1{,}209\, t/RC} \cos\,(0{,}980\, t/RC + \varphi)$$

or

$$V = i_0R + Ae^{-1{,}209\, t/RC} \cos\,(0{,}980t/RC + \varphi) \quad . \; . \; . \quad (6)$$

A and φ must now be derived from the limiting conditions. The two initial conditions are given:

$$V(t)_{(t=0)} = 0 \quad \ldots\ldots\ldots \quad (7\text{a})$$

$$i_L(t)_{(t=0)} = 0 \quad \ldots\ldots\ldots \quad (7\text{b})$$

From (7b) it follows that:

$$i_C(t)_{(t=0)} = i_0$$

and since

$$i_C = C\frac{\mathrm{d}V}{\mathrm{d}t}, \qquad \text{then} \qquad \left(\frac{\mathrm{d}V}{\mathrm{d}t}\right)_{(t=0)} = \frac{i_0}{C}.$$

For A and φ the following equations then result:

$$i_0R + A \cos\varphi = 0,$$

$$1{,}209 \cos\varphi + 0{,}980 \sin\varphi + i_0R/A = 0.$$

From this one finds that

$$A = -1{,}022\, i_0R,$$

$$\varphi = -0{,}209.$$

The complete formula for the transient characteristic is thus:

$$V = i_0R \left\{1 - 1{,}022\, e^{-1{,}209\, t/RC} \cos\,(0{,}980t/RC - 0{,}209)\right\} \quad . \; . \quad (8)$$

The results are reproduced in *fig. 6* in which curve *II* corresponds to equation (8). As unit of voltage the value i_0R is taken, as unit of time the product $RC = R\,(C_1 + C_2)$. It is clear from the figure that a certain time elapses before the voltage reaches the final value. Furthermore, in all cases except that of the oridinary resistance coupling (curve *I*)

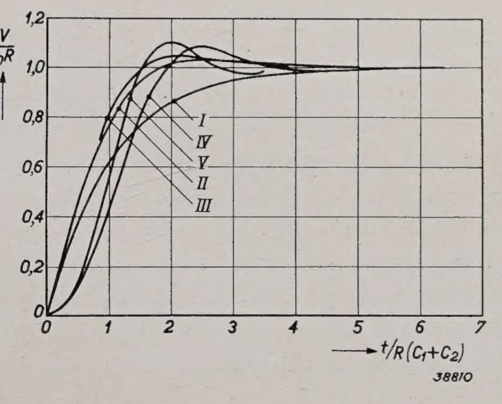


Fig. 6. Transient characteristics of the coupling networks given in fig. 4.

a certain degree of "overshooting" occurs. When the successive transient characteristics *II*, *III*, *IV*, *V* are compared, it is seen that the maximum slope in the rising part becomes steadily steeper, at the same time, however, the overshoot becomes steadily greater. It is somewhat a question of subjective judgment which of these curves should be considered as the best approach to a rectangular voltage variation. The great improvement which seems to have been obtained upon a comparison of amplitude

characteristics II and V is therefore of doubtful value for the reproduction of a rectangular voltage variation.

If an attempt is made to generalize the results here found, the question arises as to what shape of the amplitude characteristic must be considered the best. The higher the frequencies to which the amplitude characteristic of an amplifier is flat, the steeper the front of its transient characteristic, which of itself is favourable for the attainment of a faithful reproduction. As we saw above, however, with increasing steepness of the front of the transient characteristic, the tendency toward overshooting also increases. This overshoot indicates the presence of weak damped resonances which will lead to a local steep slope in the the amplitude characteristic. The attempt is often made to increase the amplification of high frequencues by means of resonance in such a way that a peak occurs in the amplitude characteristic. In that case the overshoot is found to be so strong that there can no longer be any question of an improvement in the reproduction. An extension of the flat part of the amplitude characteristic to higher frequencies will therefore involve no improvement when it is accompanied by the appearance of resonance peaks or by a large increase on the slope of the descending part of the characteristic.

With this in mind, it is not surprising that connections IV behave less favourably than connections III as far as the transient characteristic is concerned. The flat part of the amplitude characteristic is but little extended upon transition from III to IV, while the slope of the descending part has increased considerably. The transition from the coupling network I to coupling network II, on the other hand, must be considered as a very appreciable improvement: in this case the flat part of the amplitude characteristic is considerably extended, without the slope of the descending part having become much greater.

Output voltage with a given input signal

In the following way it can be understood that the knowledge of the transient characteristic is sufficient to calculate the voltage variation with

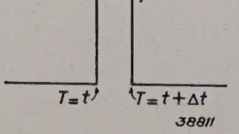


Fig. 7. Current impulse as input signal. With the help of the transient characteristic the corresponding output signal can be calculated.

any given input current. When at the moment $T = 0$ the input current jumps from 0 to 1, the voltage variation will be given by the transient characteristic $S(T)$. If this jump occurs at the moment $T = t$, the voltage variation is given by $S(T-t)$. If a current of the form indicated in *fig. 7* is taken as input current, the voltage becomes

$$\begin{aligned} V(T) &= S(T-t) - S(T-t-\Delta t) \\ &\approx S(T-t) - [S(T-t) - \Delta t S'(T-t)] \\ &= S'(T-t)\Delta t. \end{aligned}$$

Any given variable current can always be considered as a connected series of current impulses of the type represented in fig. 7 (see *fig. 8*) and having an amplitude $i(t)$.

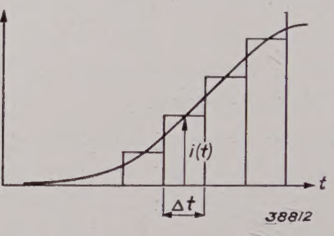


Fig. 8. Any given input signal can be built up of a number of connected current impulses.

The output voltage is obtained by adding together the contributions of all the current impulses, thus

$$V(T) = \sum_{t=0}^{t=T} i(t) S'(T-t)\Delta t.$$

which for $\Delta t \rightarrow 0$ passes over into

$$V(T) = \int_0^T i(t) S'(T-t)\, \mathrm{d}t \quad . \quad . \quad . \quad . \quad (9)$$

When $i(t)$ and $S(t)$ are given the variation of the voltage may therefore be formed by integration.

As a special case we choose a current which begins at the moment $t = 0$ and is sinusoidal. The output voltage $V(T)$ is given by the formula

$$V(T) = \int_0^T \sin \omega t S'(T-t) \mathrm{d}t,$$

which by means of simple transformations can be converted into

$$\begin{aligned} V(T) = \sin \omega T \int_0^T \cos \omega t\, S'(t) \mathrm{d}t\, - \\ - \cos \omega T \int_0^T \sin \omega t\, S'(t) \mathrm{d}t \quad . \quad . \quad . \quad . \quad (10) \end{aligned}$$

The integrals in equation (10) approach certain limiting values with increasing value of T. In other words, the voltage $V(T)$ finally takes a sinusoidal form with a given amplitude and phase. If we set

$$\int_0^\infty \cos \omega t \, S'(t) \mathrm{d}t = c(\omega),$$

$$\int_0^\infty \sin \omega t \, S'(t) \mathrm{d}t = s(\omega),$$

then finally

$$V(T) = c(\omega) \sin \omega t - s(\omega) \cos \omega t$$

and from this follows the amplitude characteristic:

$$f(\omega) = \sqrt{c^2(\omega) + s^2(\omega)},$$

as well as the phase characteristic

$$\operatorname{tg} \varphi(\omega) = s(\omega)/c(\omega).$$

This shows therefore that the transient characteristic can replace the amplitude characteristic as well as the phase characteristic.

Transient characteristic of several stages in cascade connection

Equation (9) is of direct use when it is desired to derive the transient characteristic of an amplifier with several stages from the transient characteristics of the separate stages. Let us assume that an amplifier consists of two stages, the first of which has a coupling network with a transient characteristic S_a, and the second a coupling network with a transient characteristic S_b. If the transient $0 \rightarrow 1$ is applied to the first stage, the output voltage of that stage becomes the voltage $S_a(T)$. If the amplifier valve is a pentode, this voltage is converted

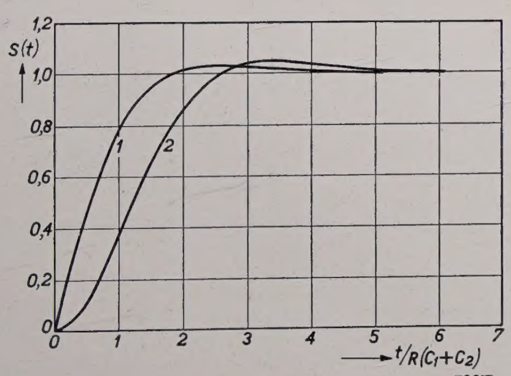


Fig. 9. 1) Transient characteristic of a stage with network *II* of fig. 4. 2) Transient characteristic of two such stages in cascade connection. The front of the characteristic becomes less steep and the peak formation more pronounced.

into a current having the same variation with time and this current is applied to the second stage having a transient characteristic $S_b(T)$. The output voltage of this second stage, which now represents the transient characteristic of the whole amplifier, can immediately be written in the following form on the basis of equation (9):

$$S(T) = \int_0^T S_a(t) S_b' \, (T-t) \mathrm{d}t. \quad . \quad . \quad . \quad (11)$$

By this "multiplication", therefore, the transient characteristic of an amplifier can be derived from those of the separate stages [5]).

As an example the transient characteristic of two similar stages in cascade connection was calculated. A characteristic for each stage like curve *II* of fig. 6 was assumed. In *fig. 9* the resulting transient characteristic is shown compared with that of one separate stage. The transient characteristic of the two-stage amplifier is somewhat less steep and shows a greater degree of peak formation. When still more stages are used this effect will in general appear even more pronounced.

High-frequency amplifiers

In the high-frequency stages of radio receivers and television receivers one is not concerned with the shape of the whole curve of the output signal, but only with the variation with time of its amplitude. It is therefore reasonable in the case of these stages to indicate as transient characteristic the variation of the amplitude of the output signal for a high frequency input signal whose amplitude jumps from 0 to 1. When the carrier-wave frequency of the output signal is high compared with the highest modulation frequencies, it is found to be capable of being represented approximately as a high-frequency alternating voltage modulated in amplitude, with the same frequency and phase as the input signal. This results in the fact that the modulation of the output signal for any given variation of the input amplitude can be derived from the above defined transient characteristic. As in the foregoing the input signal can be separated into the alternating currents during successive time intervals Δt, each of these "A.C. impulses" gives at the output side a voltage contribution of the same frequency and phase, so that the total output

[5]) The integral given is a symmetrical function of S_a and S_b, so that the transient characteristic does not change when the order of the stages is reversed. This is shown by a partial integration:

$$\int_0^T S_a(t) \, S_b'(T-t) \, \mathrm{d}t = S_a(0) S_b(T) - S_a(T) S_b(0) + \int_0^T S_a'(t) \, S_b(T-t) \, \mathrm{d}t.$$

The first two terms on the right hand side disappear since $S_a(0) = S_b(0) = 0$. If in the third term we set $T-t = t'$, the whole equation assumes the form

$$\int_0^T S_a(t) \, S_b'(T-t) \mathrm{d}t = \int_0^T S_b(t') \, S_a'(T-t') \, \mathrm{d}t',$$

which clearly shows the symmetry.

amplitude at every moment is given by the sum of the amplitudes of all the voltage contributions.

In an earlier article in this periodical it was pointed out that many coupling networks of high frequency amplifier stages can be derived by a simple transformation from the coupling networks of a video-frequency amplifier [6]). It is only necessary to time each capacity with a self-induction connected in parallel with a definite frequency f_0 in the middle of the television band, and bring every self;induction into resonance at that same frequency by means of a series condenser.

If one compares the transient characteristics of a video-frequency coupling network and of a high-frequency coupling network derived from it, it is found that they both possess exactly the same shape, but that the latter varies twice as slowly with time as the former. This corresponds entirely with the property of the high-frequency network derived in the above mentioned article, that its amplitude characteristic plotted as a function of $2(f-f_0)$ has the same variation as the amplitude characteristic of the video-frequency coupling network plotted as a function of f. A proof of this statement may therefore be omitted.

High-frequency amplification of carrier wave and one side band

The high-frequency coupling networks introduced in the above with branches which are tuned to a frequency f_0 possess an amplitude characteristic symmetrical on both sides of this frequency, so that two signals with the frequencies $f_1 = f_0 + \Delta f$ and $f_2 = f_0 - \Delta f$ are amplified to the same degree. If f_0 is chosen equal to the carrier-wave frequency, therefore, the two side bands will furnish the same contribution to the output signal.

At the present time it is often recommended that the receivers should be so arranged that in addition to the carrier wave they will receive only one side band. This is chiefly because then with a given width of the frequency band for which the amplifier is sensitive twice as high modulation frequencies can be amplified. The carrier wave then lies at the upper or lower limit of the frequency band in question, and is usually displaced so much to one side that the amplication for the carrier wave has already fallen to one half. We shall now discuss briefly the results which are thereby obtained for the case of one stage which contains a simple circuit with damping in parallel.

In the very first place it is found that it is impossible with such an amplifier to derive the behaviour of the output amplitude for any given behaviour of the input amplitude from the transient characteristic. This is connected with the fact that the output signal of this amplifier does not exhibit pure amplitude modulation upon a sudden change in amplitude of the input signal but also varies in phase and frequency. The first reaction to a discontinuous change in the input signal is the appearance of a free oscillation with a frequency lying in the middle of the band to which the amplifier is sensitive. This oscillation is gradually damped: only the forced oscillation then remains whose frequency, as stated above, lies at the edge of the sensitive region.

The result of this frequency modulation is that the contributions of the different preceding A.C. impulses to the output voltage present at a definite single instant differ mutually in frequency. The amplitude of the output voltage is then no longer given by the sum of the amplitudes of all the contributions, so that the variation of the output voltage can no longer be calculated by integration over the contributions of all the preceding A.C. impulses, but it must be treated separately for each variation of the input current.

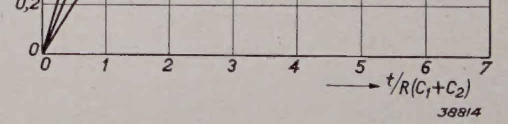


Fig. 10. Variation of the output amplitude in the case of single side-band amplification upon the use of a circuit with damping in parallel.
1 amplitude of the input current $0 \rightarrow 1$
2 amplitude of the input current $1 \rightarrow 0$
3 amplitude af the input current makes a small jump $i_3 \rightarrow i_3 + \Delta i_3$. In this case $S(t)$ stands for the output amplitude divided by Δi_3.

In *fig. 10* the behaviour of the amplitude modulation of the output signal as a function of the time for different input signals is shown for the case of single side-band reception. Curve *1* shows the behaviour with the transient $1 \rightarrow 0$. For the sake of comparison with the preceding curve, curve *2* is plotted in the reverse direction. It may be seen that there is here a very great difference in the shape of the curves, Curve *1* exhibits a peak for-

[6]) See the article referred to in footnote [4]).

mation of 20 per cent, while in the shape of curve *2* the oscillation is completely damped.

Curve *3* represents the variation of the amplitude modulation of the output signal when the jump in amplitude of the input signal is only small. In that case a jump in one direction and one in the opposite give symmetrical results, which approximately resemble curve *1*.

For television signals which are so modulated that the amplitude increases with increasing brightness of the picture (positive modulation) we may draw from curves *1* and *2* the conclusion that a transition from black to white will be sharper and will exhibit more peak formation than a transition from white to black. The latter has exactly the same behaviour in the output signal as if the carrier-wave lay in the middle of the sensitive band. Therefore if we assume that the worst transition determines the quality of the picture, we would reach the conclusion that the use of a single side band with a given total band width does not give better quality than the use of two side bands. If, however, we assume that the quality of the picture is determined chiefly by the reproduction of small contrasts (curve *3*), there is considerable improvement in the definition.

To what degree this may be considered as an improvement in the quality of the picture cannot be decided on the bases of our example. We considered an ordinary oscillation circuit which is analogous to a simple *R-C* circuit as far as its transient characteristic is concerned. Since in spite of this in the case of single side-band reception a 20 per cent overshoot occurs, it must be feared that a complete receiver will exhibit much greater oscillations, the combatting of which may be very difficult.

A mathematical treatment of single side-band reception with fairly complex networks is quite complicated, so that no detailed theoretical investigations have yet been carried out in this direction. It is, however, not dificult to determine the transient characteristics of receivers experimentally. Difficulties might here be expected because of the necessity of measuring a transient which occurs only once. This difficulty can, however, be avoided by applying to the input a block signal as in fig. 2 or a high-frequency signal with a block-shaped amplitude variation. If the period of this block signal is taken large enough the transition phenomena which occur due to a given transient will have become practically equal to zero by the beginning of the following transient. In this way the transient characteristic is found continually repeated, so that it can be made visible, for instance by means of a cathoderay oscillograph.

AN APPARATUS FOR TREATMENT WITH INFRARED RADIATION

by A. van WIJK.

621.384 : 615.83

Various local affections, such as rheumatism, can be successfully treated by heating the tissue by means of an irradiation apparatus. The wave length of the radiation can best be chosen so that the greatest possible amount of energy is absorbed with a given increase in temperature of the tissue close to the surface of the skin. This means that the absorption coefficient of the body must be low for the radiation in question. The most favourable radiation for this purpose is the region of red and infrared with wave lengths from 0.7 tot 1.3 μ. Radiation of longer wave lengths is highly absorbed especially by water, that of shorter wave lengths, by the red colouring matter in the blood.

In this article the Philips apparatus for infrared irradiation is described. The radiation is excited with the help of an incandescent filament lamp surrounded by a filter of running water. This apparatus furnishes practically exclusively radiation with the desired wave lengths, while in the case of the ordinary incandescent bodies of low temperature only a few per cent of the radiation has the desired wave lengths. On the basis of tests it is shown that with the new apparatus about three times as great an intensity of radiation can be applied as with the ordinary apparatus.

In the case of various local afffections (for instance rheumatism, inflammations) which do not lie too deep under the skin, but also in the case of diseases of the internal organs, use is made by doctors of the so-called infrared treatment, for curing or for relieving pain. It must be assumed that the favourable action is primarily a result of the heating of the tissue which occurs. Whether or not in addition a photochemical action of the radiation must also be assumed is uncertain, although this possibility is taken into account.

In the application of infrared irradiation the aim is as a rule to increase the radiation intensity as much as possible in order to heat the tissue in the the neighbourhood of the affection as highly as possible.

At all points in the tissue the heat freed per unit of time and per unit of thickness of layer is proportional to the local intensity of radiation. Since the radiation is strongly absorbed in the tissue and the intensity thus decreases rapidly with penetration, the heating effect in the layers first traversed is very much greater than at a somewhat greater depth. The natural limitation of the intensity of the irradiation applied is therefore furnished by the heating effect on the outermost layers of tissue, *i.e.* the skin and the layer directly beneath it, in which lie the organs of feeling. This heating may not exceed a definite value without causing intolerable pain.

The degree of heating depends not only upon the intensity but also upon the nature of the radiation employed, *i.e.* on the wave length, or the wave length region in which the energy is emitted. The wave length has a great influence on the absorption of the radiation in the tissue [1]). The slighter the absorption the greater the depth to which it acts and the greater the intensity of irradiation which can be applied before the absorption of energy in the outermost skin layer becomes so great that pain is felt (*cf. fig. 1*). It is therefore important to choose a type of radiation for which the absorption is as small as possible.

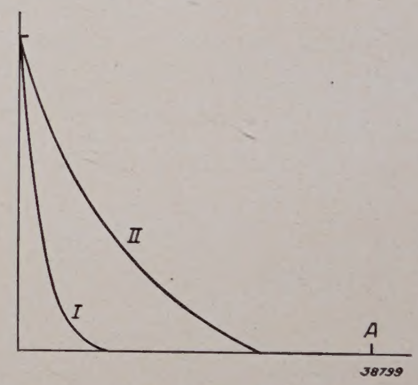


Fig. 1. Diagram of the variation of the energy absorbed per unit of time and per unit of thickness of layer as a function of the depth in the tissue,
I for radiation with high absorption,
II for radiation with slight absorption.
The irradiation intensities are so chosen that the absorptions directly under the skin are equal. The surface of the curves gives the total energy absorbed per unit of time, which therefore in the case of curve *II* is considerably greater than in the case of curve *I*. For a point deeper than the absorption region, *A* for instance, this energy determines the heating effect which takes place by conduction.

In practice this requirement is not at all satisfied at present in infrared treatment. The most commonly used irradiation apparatus contains as source of radiation an electrically heated filament, in the open air, whose temperature varies from 500 °C (barely incandescent) to 1 000 °C (orange-red incan-

[1]) *Cf.* for example G. Miescher, Strahlenther. **61**, 578, 1938.

descence). The relative composition of the radiation of such bodies is approximately described by Planck's law for the radiation of "black bodies" [2]).

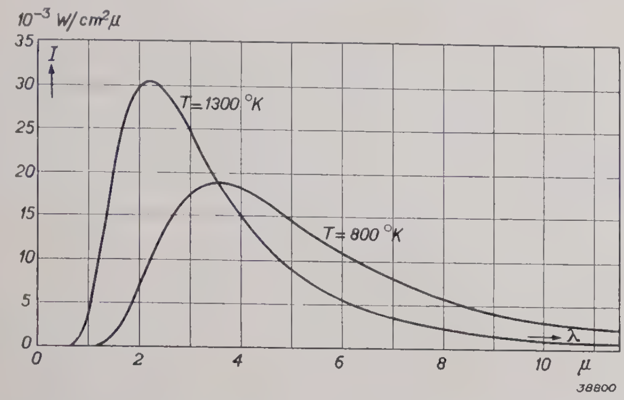


Fig. 2. Irradiation intensity in W/cm² per wave-length region of 1 µ as a function of the wave length, for black bodies with temperatures of 800 °K and 1 300 °K, with a total irradiation intensity of 0.1 W/cm².

Fig. 2 gives the variation of the radiation intensity as a function of the wave length for the temperatures mentioned, which correspond to absolute temperatures of 800 °K and 1 300 °K [3]). The curves are drawn for cases of equal irradiation intensity, namely 0.1 W/cm². The maxima of the radiation intensity lie far in the infrared for both temperatures, at wave lengths (λ) of about 3.6 and 2.2 µ, respectively. Only a negligibly small fraction of the radiation lies in the visible region ($\lambda < 0.8$ µ). This is in agreement with the customary name of "infrared treatment" as compared with the "heating by means of radiation" considered in this article.

In principle, however, radiation of other wave-length regions might just as well be used, since the heating effect of the absorbed radiation is the same for all wave lengths, namely 860 kcal/kwh. The fact that infrared radiation has been chosen, and that sources of radiation of low temperature have thus been arrived at for generating this radiation is based upon the very wide-spead misconception that only infrared radiation furnishes heat. which misconception is expressed in the term "heat radiation" for infrared. The origin of this misconception may be sought in the fact that in the case of practically all existing sources of radiation (electric lamp, candle, fire) by far the greatest part of the energy emitted lies in the infrared spectral region, so that what one feels of the radiation is mainly due to this region. This is, however, only a question of quantity and not of quality.

The lower the temperature the greater the proportion of the radiation emitted in the infrared. On the basis of the misconception indicated, and in the mistaken expectation of a high efficiency, this has led to the use of sources of radiation of low temperature.

The problem is not, however, to obtain the highest possible percentage of infrared radiation, but to choose a kind of radiation which permits the highest possible load on the skin, *i.e.* as already explained, a kind of radiation which is absorbed as little as possible by the tissue. If we now recall that the living tissue consists for the most part of water, we see that the radiation which is strongly absorbed by water cannot have a very great depth of penetration into the tissue. *Fig. 3* shows the absorption curve [4]) of water, as well as the transmission calculated from it with thicknesses of layers of 1, 5 and 10 mm. It is clear that even with thin layers practically no radiation of $\lambda > 1.35$ µ is transmitted

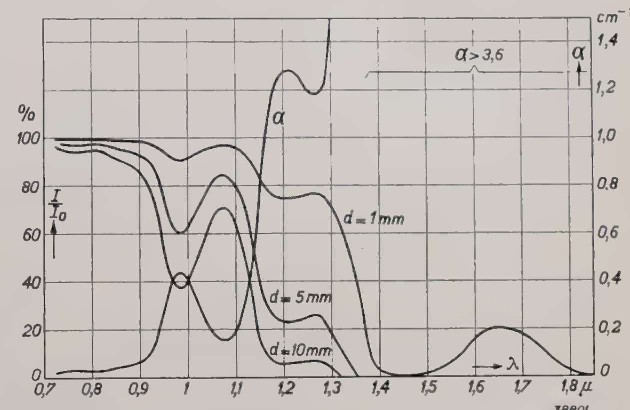


Fig. 3. Absorption index α and transmission I/I_0 for water at different thickness of layer d. The absorption index α is defined by the relation:

$$\frac{I}{I_0} = 10^{-\alpha d}.$$

At wave lengths greater than 1.35 µ water exhibits strong absorption.

(with a thickness of 1 mm a transmission region with a maximum of 20 per cent may be observed at 1.65 µ, at 2 mm the height of this maximum has been reduced to 4 per cent, at 3 mm to 0.8 percent). It may therefore be concluded immediately that radiation with $\lambda > 1.35$ µ can never reach the deeper layers of tissue, but is entirely absorbed in the outer layer, and that it is therefore unsuitable for the therapy in question.

Radiation of too short wave lengths is also unfavourable for the therapy in question. For example, ultra violet light is strongly absorbed and the same

[2]) For practical applications of Planck's radiation formula see for example the tables of W. de Groot, Physica **11**, 265, 1931 or Jahnke-Emde, Funktionentafeln, Teubner (Leipzig, Berlin) 2nd edition, 1933 p. 46.

[3]) Absolute temperature in °K = temperature in °C + 273°.

[4]) J. R. Collins, Phys. Rev. **26**, 771, 1925.

is true of visible light with the exception of the extreme red. The colouring matter of the blood is to a large extent responsible for this absorption. Direct transmission tests with layers of tissue have shown that the maximum of transmission lies between 0.7 and 1.35 μ [5]), whereby the long wave end of the curve corresponds to that of water, and the short wave end to that of oxyhaemoglobine [5]), *i.e.* the red blood colouring matter in the oxidized form (arterial blood).

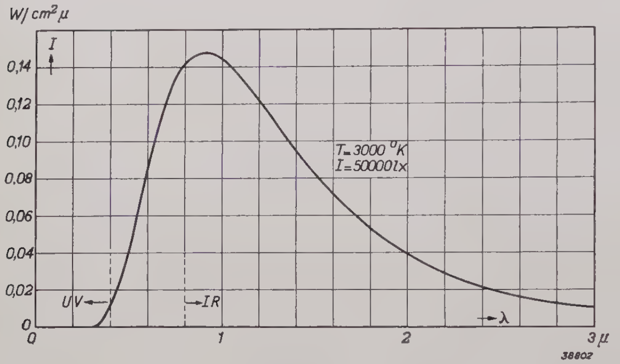


Fig. 4. Irradiation intensity as a function of the wave length for an incandescent body of tungsten with a temperature of 3 000 °K, with an illumination intensity of 50 000 lux.

The radiation emitted by black bodies at low temperature is very unfavourable in connection with the transmission. At 1300 °K only 4 per cent of the radiation has a wave length shorter than 1.35 μ; at 800 °K this proportion is even less than one per thousand (*cf.* fig. 2). By choosing a higher temperature, however, it is found possible to obtain radiation of which a much larger percentage belongs to the wave-length region of maximum transmission. *Fig. 4* shows the distribution of the radiation from tungsten at a temperature of 3 000 °K. The curve is valid for a case in which the illumination intensity amounts to 50 000 lux. In this case the radiation density is 0.168 W/cm² (calculated to $\lambda = 3$ μ; the tungsten filament is always surrounded by a bulb of glass or quartz which absorbs radiation of longer wave length). The distribution of the radiation over the different wave-length regions is shown in the following table.

Table I

wave-length region	radiation density	
	W/cm²	%
infrared $\lambda > 1.35$ μ	0.062	37
infrared 1.35 $\mu > \lambda > 0.7$ μ	0.088	52
visible 0.7 $\mu > \lambda > 0.4$ μ	0.018	11
ultraviolet $\lambda < 0.4$ μ	$0.45 \cdot 10^{-5}$	0.27

As the table shows, 0.088 W/cm² of the radiation, *i.e.* 52 per cent, falls within the favourable region from 0.7 tot 1.35 μ, in addition, however, 37 per cent falls in the unfavourable region $\lambda > 1.35$ μ which is too much absorbed on the surface of the tissue. By filtering the radiation through a layer of water, that part which contains the unfavourable wave lengths can be removed in advance, and the composition becomes much better, in the sense that a still higher percentage lies in the region 0.7—1.35 μ. *Fig. 5* shows the spectral distribution of the radiation behind water filters of 5 and 10 mm, respectively. The percentages in the region 0.7-1.35 μ are 74 per cent and 70 per cent, respectively; practically all of the remainder lies in the visible. As may be seen from the decrease in the percentage upon increase in the thickness of the water layer from 5 to 10 mm, a further increase in this thickness is of no advantage.

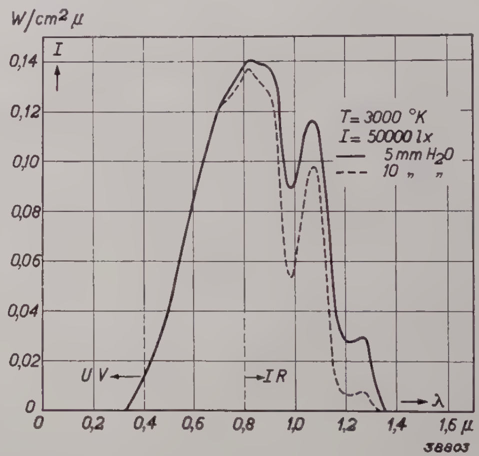


Fig. 5. Irradiation intensity as a function of the wave length for a tungsten wire at 3 000 °K with water filter, at an illumination intensity of 50 000 lux. Continuous line, water filter 5 mm thick. Broken line, water filter 10 mm thick.

The Philips apparatus for infrared irradiation

The Philips apparatus for infrared irradiation (*cf. fig. 6*) contains an electric lamp of 750 W with a filament temperature of 3 000 °K, surrounded by a layer of water about 6 mm thick. It is necessary to use running water, since otherwise it would quickly boil, due to the large quantity of energy it absorbs. A comparison of the curves of figs. 4 and 5 shows that with a layer of water 5 mm thick about 54 per cent of the energy emitted is absorbed in the water, in addition to which is the heat which reaches the glass bulb of the lamp by convection and the energy absorbed in the bulb, both of which can also be given off to the water. Direct measurement by determination of the temperature differ-

[5]) *Cf.* G. Hoffmann, Strahlenther. **65**, 477, 1939; also U. Henschke, Strahlenther. **66**, 646, 1939; this survey, from which various data have been borrowed, contains a detailed bibliography.

ence of the incoming and outgoing water gave an energy of 560 watts absorbed by the water.

By means of an adjustable reflector the radiation can be more or less concentrated as required. For the sake of this possibility it is also important that the temperature of the radiation element should be high, so that its dimensions need only be small. In our case the largest dimension is about 1 cm. Since the total radiation flux emitted per unit surface of the source is proportional to the fourth power of the temperature, at a temperature of 800 °K the surface area would have to be $(3\,000/800)^4$ = about 200 times as large for an emission of the same energy, and the reflector would also have to be correspondingly very much larger in order to obtain the same concentration of beam and adjustability of beam formation.

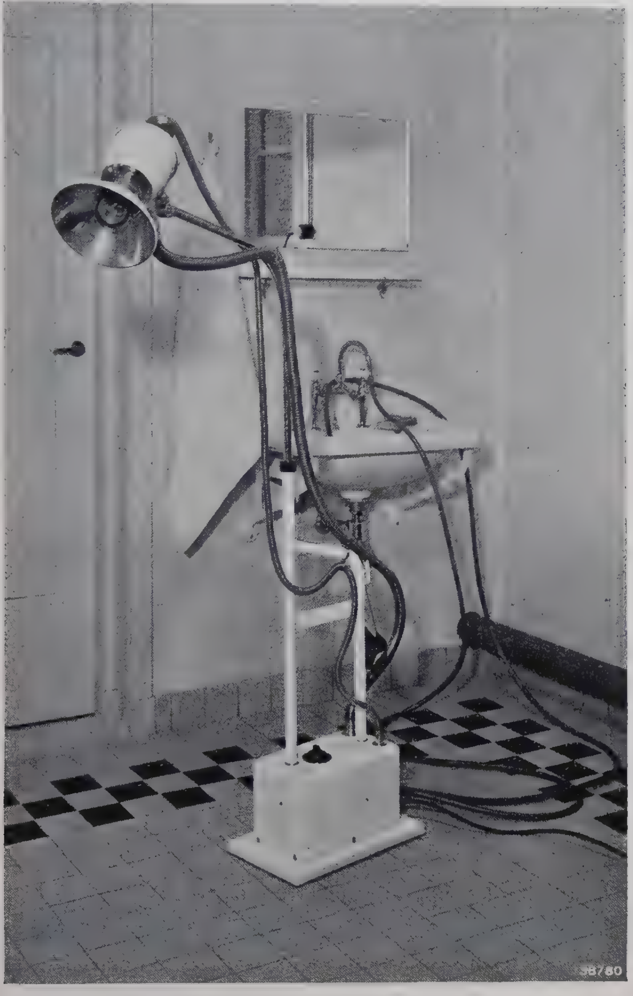


Fig. 6. Philips apparatus for infrared treatment.

The lamp is fastened to an adjustable standard, similar to that of the Philips "Biosol" apparatus [6]). The lamp (with reflector) can be rotated through angles of 60° about two mutually perpendicular axes, so that the beam can easily be directed upon the desired part of the body. In the case of the standard there is a transformer with separated windings, by which the mains voltage (A.C. voltage 220 V) is transformed to 15 volts. The lamp current (50 Δ) is conducted to the lamp through a cable surrounded by a flexible metal sheath; through a second thick metal tube run the rubber inlet and outlet tubes for the filter water.

Properties of different sources of radiation

It was noticed by Henschke [7]) that the radiation tolerance of the skin (*i.e.* according to the above the maximum intensity of the incident radiation which can be borne without pain), in contrast to many other subjective quantities, can be fairly sharptly determined, and with a given composition of radiation it varies very little for different individuals. During short times very high irradiation intensities can be borne, but as the time of irradiation increases the permissible intensity decreases and approaches an asymtotic value. In *fig.* 7 the experimentally found time during which a given radiation intensity can be tolerated is plotted as a function of this intensity for radiations of different composition [8]). It is evident how relatively sharply the limit is defined of the radiation intensity which can be tolerated for a long time (*i.e.* longer than 3 min.) and how widely the skin tolerance for radiation differs for the different kinds of radiation.

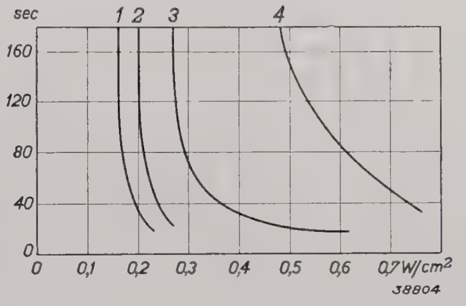


Fig. 7. Time during which the skin can tolerate a radiation as a function of the irradiation intensity, for the four different sources of radiation of table II.

In *table II* the tolerances deduced from fig. 7 are given for long irradiation times.

According to the table, with the Philips apparatus for infrared irradiation a skin dosage can be given which is approximately 3 times as great as the

[6]) See Philips techn. Rev. **2**, 18, 1937.

[7]) See the article referred to in footnote [5]).

[8]) The values found by us deviate appreciably from the figures given by Henschke (footnote [5]). The latter are about 30 times as large. It seems probable to us that the values given by Henschke are given per minute and not per second as he states.

infrared sources now being used, and consequently a correspondingly greater heat effect can be attained. The nature of the radiation is such that the maximum depth effect is obtained. Nevertheless in this case also at any great depth (several mm or more) the heating effect is mainly due to conduction and not to radiation which has penetrated that far, since the latter is already much too attenuated (see fig. 1).

Table II

Source of radiation	Temperature	Skin tolerance for long-continued irradiation
1) Ordinary infrared irradiation apparatus (radiator)	1 300 °K	0.16 W/cm²
2) Electric lamp under low load	2 200 °K	0.20 W/cm²
3) Electric lamp under high load	2 900 °K	0.27 W/cm²
4) Philips' infrared irradiation apparatus	3 000 °K	0.47 W/cm²

The temperature increase as a function of the depth in the tissue has been determined by different investigators. It may be seen from the measurements that at a greater depth than about 10 mm no increase in temperature can be observed, even with the optimum composition of the radiation. Since infrared irradiation is also often used for more deeply lying affections, it must be assumed that if there is any effect at all it cannot be caused by direct heating, but by an indirect effect, for instance reflective. Another possibility of explanation is that there is photochemical action and to an important extent. Even at a great depth where the attenuation is so great that there can be no question of a heat effect when radiation in the region 0.7-1.35 μ is considered, the intensity is still great enough to exert a possible photochemical effect.

It cannot reasonably be expected that radiation with a wave length longer than 3 μ can be important in such a photochemical effect; the radiation quanta in that region are so small that they can only promote chemical reactions which require such a low activation energy that they would also be brought about by thermal agitation. Therefore its photochemical action plays any essential part in infrared irradiation, the radiation which is furnished by the Philips apparatus will be favourable, not only because of its greater depth of penetration, but also because of the greater energy of the radiation quanta.

It is interesting to note that the radiation of the sun is also filtered by water before it reaches the earth, and to about the same degree as that chosen for the Philips apparatus. The amount of water vapour in the earth's atmosphere is such that if it were all condensed a layer would be obtained whose thickness would be of the order of 1 cm. Thus the amount of water in the atmosphere above the Astrophysical Observatory on Mt. Wilson corresponds to an average thickness of 0.69 cm, while the extremes are 0.2 and 2.8 cm. At the long wave end the boundary of the spectrum of the Philips apparatus for infrared irradiation is about the same as that of the sun's spectrum. The maximum of the radiation intensity of the sun lies in the visible region (about 0.5 μ), that of the Philips apparatus at about 0.8 μ.

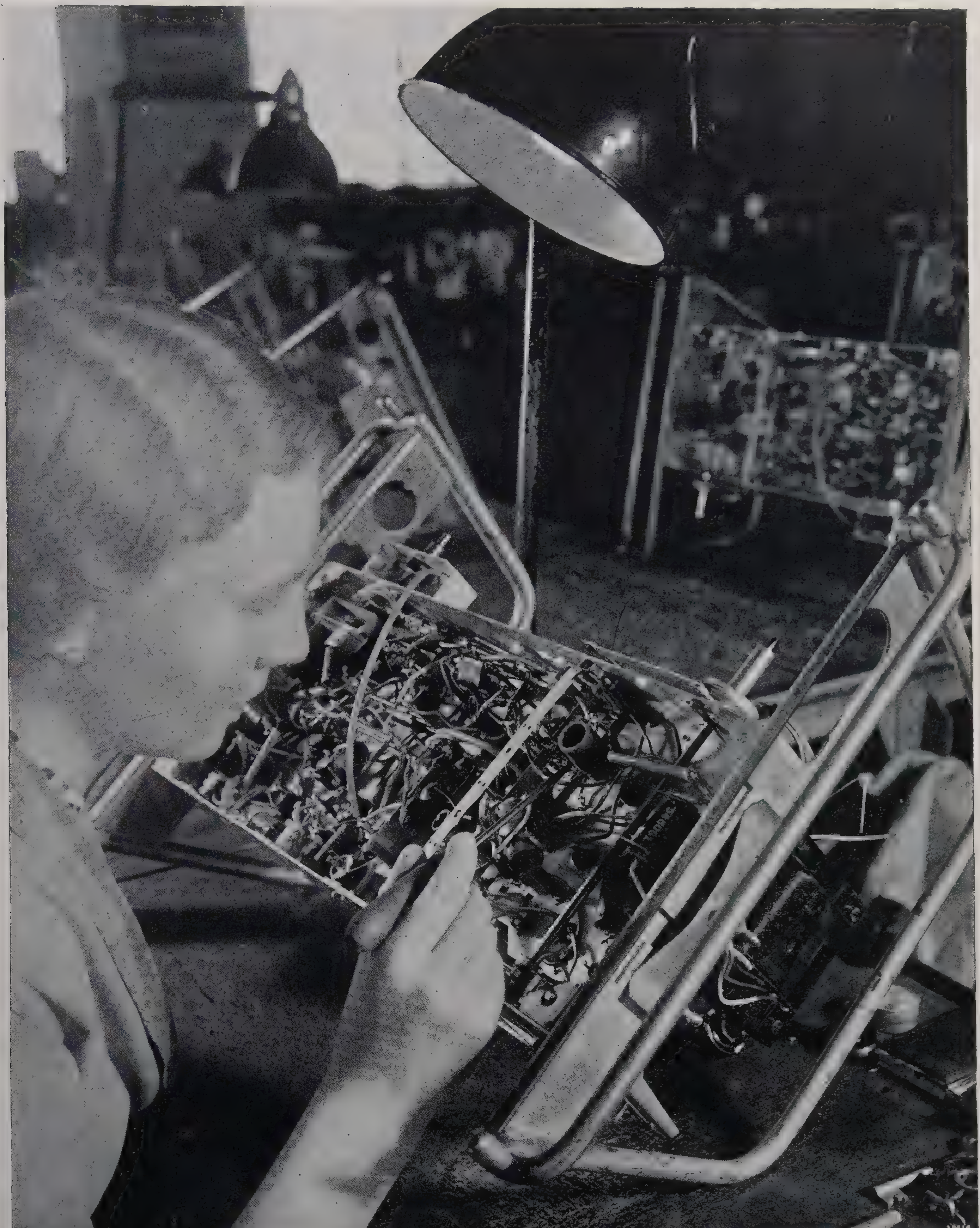
About 35 per cent of the sun's radiation lies in the wave-length region of greatest transmission (0.7-1.35 μ), with the Philips apparatus this figure is about 70 per cent, so that the tolerance of the skin for the sun's radiation will be lower than for that of the apparatus.

The intensity of the sun's radiation on earth amounts to about 0.1 W/cm² under favourable conditions, *i.e.* it is of the same order of magnitude as was found in table II for the skin tolerance with different compositions of radiation. If the intensity of the sun's radiation is increased to for instance two or three times the original value by means of a concave mirror, the limit of the skin tolerance is actually reached.

The cooling due to air currents is of great importance on the experimentally found tolerance. Even with quite a low wind strength more can be tolerated than in a perfect calm. The fact that on certain days the sun can "burn" so much is probably rather a result of calm air than of a particular spectral composition of the sunlight (due for example to an extremely small water content of the atmosphere).

In the application of artificial radiation also, by cooling the skin either by a current of air or by a glass cuvette with water cooling pressed against the skin (compressor), the radiation tolerance can be considerably increased. This fact is used by some doctors; due to the great influence of the heat of conduction on the temperature distribution resulting in the tissue, however, this does not immediately bring about an increase in the temperature obtained at greater depths, Upon strong cooling (compressor with water) of the surface of the skin, a decrease may even occur. Any possible photochemical effect, however, can in this way be increased in any case, since the permissible irradiation intensity becomes greater.

TESTING THE CONTACTS IN A RADIO RECEIVER



The large number of connections in a radio receiver made by soldering, welding or in any other way, where a fault in one single connection may upset the functioning of the whole set, makes various kinds of tests essential. Moreover, care must be taken that the manner of making the connections ensures good quality for a long time. To fulfil this requirement a large number of checks and random tests are unavoidable, however time-consuming they may sometimes be.

A DISCHARGE PHENOMENON IN LARGE TRANSMITTER VALVES

by J. P. HEYBOER.

537.521.7 : 621.396.615.1

In transmitter valves a flashover sometimes occurs between the electrodes under high voltages in spite of a good vacuum (Rocky Point effect). In large valves this phenomenon may result in considerable damage, especially to the filaments, if no precautions are taken. The damage can be explained qualitatively, and to some extent also quantitatively by the ponderomotive forces which occur between different branches of the filament as a result of the current which flows through these branches when such a flashover occurs. The article gives several simple calculations connected with this and describes several experiments with a model in which the phenomena observed in practice could be imitated. In conclusion the way in which the harmful results of a flashover can be avoided are discussed.

In modern transmitter valves there is a vacuum of 10^{-7} to 10^{-8} mm Hg. Not only is the high vacuum of importance for the satisfactory functioning of the cathode, which must furnish the emission current in the valve and upon which gases would exert a harmful effect, but also for obtaining adequate insulation between the different electrodes. This is of particular importance since in the largest water-cooled transmitter valves peak voltages of about 40 kV may occur, while the distance between the electrodes, for example between anode and grids, amounts to only a few centimetres. With too high a gas pressure the ionization of the gas molecules by the fast electrons would quickly lead to the occurrence of a continuous gas discharge in the valve. The vacuum is most simply controlled by measuring directly the ion current which flows to the control grid (which is at a negative voltage) as a result of the ionization.

From time to time the insulation between the anode and the other electrodes suddenly disappears and a flashover occurs inside the valve. This occurs in such a way that neither before nor after such a flashover is any increased ion current to the grid measured. The phenomenon may not therefore be ascribed to a gradual depreciation of the vacuum, but it must be assumed that during the functioning of the valve, due to some cause or other, a small quantity of gas is suddenly freed from one of the electrodes. This results in a flashover, while directly afterwards the gas disappears again, probably by absorption in the electrodes or in the getter which is usually present.

The phenomenon described has long been known and is usually indicated in the literature under the name of "Rocky Point effect" from the name of an American transmitting station where the phenomenon was first observed.

Wat are the results of the Rocky Point effect on the transmitter valve? Low power valves, for instance of 100 W, withstand such a brief discharge without the slightest trouble. In the case of valves of high power, however, the discharge may lead to damage. This is understandable when the connections and construction of these valves are considered.

The anode voltage of a transmitter valve is usually supplied by a rectifier with a smoothing filter, which filter is terminated by a condenser of fairly large capacity (in large valves 20-40 μF). Between the anode and the rectifier a choking coil is further included in order to prevent the high-frequency voltage of the anode from reaching the rectifier. The supply arrangement thus takes on the form shown in *fig. 1*. In ordinary use the condenser C is charged to the anode D.C. voltage, which in large valves may amount to 10 to 20 kV.

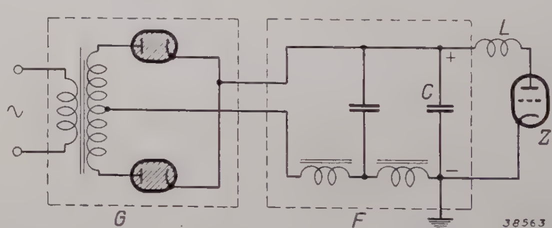


Fig. 1. Diagram of the supply arrangement of a transmitter valve (Z). G rectifier, F smoothing filter.

At the moment when a flashover occurs in the valve, the anode-cathode space functions as a short circuit. The condenser is thus discharged *via* the choke L and very large discharge currents may occur which seek a path to earth through the valve. A consideration of *fig. 2a* and *b* in which the construction of a large water-cooled transmitter valve, and particularly the construction of the cathode, is shown diagrammatically furnishes some insight into the path which the discharge currents will choose. The cathode is a tungsten filament which consists as a rule of two or more branches connected in parallel. The wires of each branch are strung in a zigzag in the direction of length of the valve, while

about them, arranged around the circumference of a cylinder, wires of one or more cylindrical grids and finally the cylindrical anode are placed. In fig. 2*b*, in which the cathode is shown flattened out, it may be seen that the beginnings of both branches come together in an earthed supply terminal P, and in the same way the ends in a second supply terminal. Upon a flashover from anode to earth the current will probably now go mainly to the wires AP and BP and flow off to earth through these wires.

Upon the occurrence of a flashover therefore the

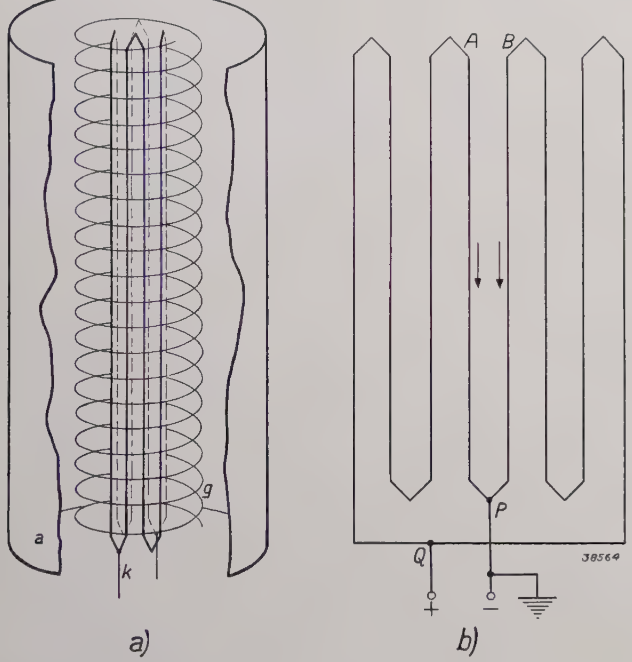


Fig. 2. *a*) Electrode system of a large water-cooled transmitter valve (triode). Around the filaments k which are strung as lines on the development of a cylinder, the control grid g is wound in the form of a spiral, while about that in turn is placed the cylindrical anode a.
b) Flattened out cathode of the water-cooled transmitter valve in question; it consists of two branches connected in parallel, each having four tungsten filaments. The two branches are fed by the common terminals P and Q, P being earthed.

adjacent wires AP and $B\ P$ may conduct very high currents; as a result there is not only considerable heat development, but at the same time large ponderomotive forces occur between the two wires. It is easily understandable that these forces may cause appreciable deviations or even permanent changes in shape of the wires.

In practice indeed such a deformation of the filament has several times been observed after a flashover, and the deviation of the wires was sometimes such that mutual contact or contact with the control grid occurred. In one case even one of the wires was torn free at the terminal. At the same time traces of the discharge were observed on the filaments, sometimes in the form of many-branched figures, usually as irregular cavities in the wires.

While these facts are explained qualitatively by the above sketched mechanism, it is also desirable to obtain a more quantitative picture of the phenomenon. The calculations and experiments undertaken to this end will be discussed briefly in the following, while a discussion will also be given of the way in which the damage can be avoided.

The whole calculation may be divided into three parts: 1) the discharge currents, 2) the forces hereby exerted on the filaments, 3) the deviations of the wires thereby caused. (The effect of the heat development will not be considered).

Calculation of the discharge current

For the calculation of the discharge current we begin with the diagram of fig. 1 in which the condenser C is charged to a voltage V and at the moment $t = 0$ is dicharged *via* the self-induction L and a resistance R. The latter, in ordinary connections, consists only of the loss resistances in coil and condenser and of the resistance of the filaments AP and BP in parallel. We assume that these filaments are traversed by the current in their full length, from A to P and from B to P.

With the help of alternating current theory the following expression is found for the discharge current $i(t)$:

$$i = i_m \sin \beta t \, e^{-at}, \quad \ldots \ldots \quad (1)$$

where

$$\left.\begin{aligned} i_m &= V/L\beta, \\ a &= R/2L, \\ \beta &= \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2}. \end{aligned}\right\} \quad \ldots \quad (2)$$

According as a real or an imaginary value is obtained for β (the latter is the case according to equation (2) only with sufficiently large damping R), the expression (1) will represent a damped sinusoidal vibration or an aperiodically varying function.

As an example let us consider a case in which defects were actually caused by the Rocky Point effect. In this case $V = 12$ kV; $L = 1\,950$ μH; $C = 32$ μF. Each filament (at the working temperature of 2 500 °K) had a length $l = 10.63$ cm and a diameter $d = 0.0892$ cm; with the specific resistance of tungsten at the working temperature (73.9×10^{-6} ohm cm) a value of about 0.07 ohm is calculated for the resistance of the two wires in parallel. As the total resistance of the dicharge circuit (in which are included the loss resistances C and L) we therefore

assume the round value $R = 0.1$ ohm. With these values we obtain

$$i_m = 1\,540 \text{ A}; \alpha = 25{,}6 \text{ sec}^{-1}; \beta = 4\,000 \text{ sec}^{-1}.$$

The current is thus actually found to reach very high values. Its variation with time (equation (1)) is shown in *fig. 3*. It may be seen that the discharge has a rapidly oscillating character (frequency $\beta/2\pi = 640$ c/s), while the damping is such that the current amplitude after about 0.3 sec., *i.e.* 20 cycles of the oscillation has fallen to one half.

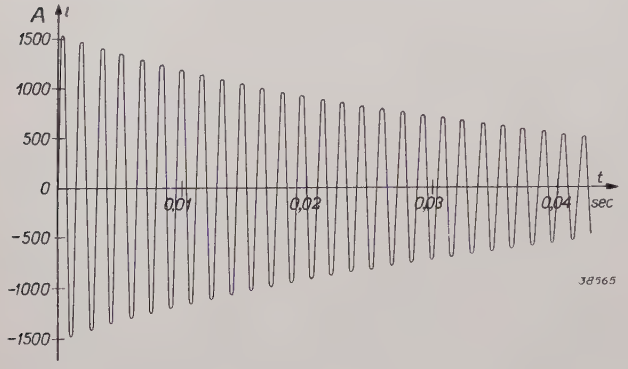


Fig. 3. Variation of the current i upon discharge of a condenser of 32 μF charged to 12 kV, *via* a self-induction of 1 950 μH and a resistance of 0.1 ohm.

Calculation of the mechanical forces

We shall assume that the current is divided equally between the two wires, so that each wire bears the current $i/2$. If r is the distance between the wires the magnetic field strength which the current in one wire exerts on the other wire is

$$H = \frac{i}{r}\,.$$

Due to the fact that this other wire itself carries the current $i/2$, it experiences a force per unit length of

$$p = H \cdot \frac{i}{2} = \frac{i^2}{2\,r} \text{ dynes/cm},$$

when r is given in centimetres and i in electromagnetic units. If we measure i in amperes, then

$$p = \frac{i^2}{200\,r} \text{ dynes/cm}. \quad . \quad . \quad . \quad (3)$$

Since the current has the same direction in both wires, the direction of p is such that the wires are always drawn toward each other. If in (3) we fill in the expression (1) for the current, we obtain

$$p = \frac{i_m{}^2}{400\,r}\,(1-\cos\,2\beta t)\;e^{-2\alpha t} \quad . \quad . \quad (4)$$

In *fig. 4* this variation of the force with time is plotted with $r = 0.617$ cm as in the example considered. If we neglect the damping for the time being the force may be described roughly as follows:

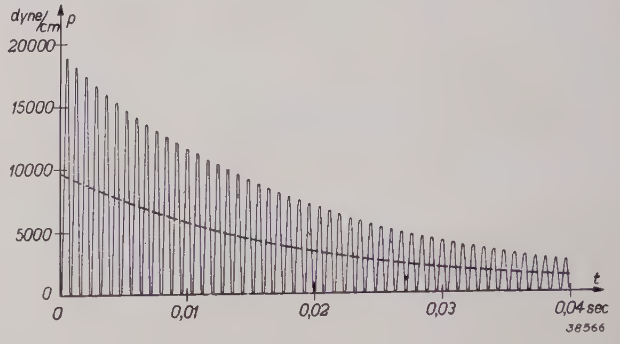


Fig. 4. Variation of the force p which is exerted by the discharging current of fig. 3 on 1 cm of each of the two filaments AP and BP.

from the moment $t = 0$ a constant force of the magnitude

$$p_0 = \frac{i_m{}^2}{400\,r}\,, \quad . \quad . \quad . \quad . \quad . \quad (5)$$

acts upon each of the two wires, while upon this is superposed a force with the amplitude (5) varying at the frrquency $2\beta/2\pi = 1\,280$ c/s. With the given values of iF and r, pe becomes 9 620 dynes or about 10 g per cm length of the wire.

The damping is here twice as great as for the current, so that the force has fallen to one half after about 0.15 sec.

The bending of the filaments

The filaments may be considered as rods which will be set vibrating by the force (4). The quantity in which we are interested is the maximum deviation which the rod thereby makes. The fact that these deviations will not be only very small can easily be understood when it is considered that the wire in our case, according to the data in *table I* weighs about $1^1/_4$ g, while at the beginning an

Table I

Data about the filaments of the valve in question for the working temperature of 2 500 °K.

Length	$l = 10.63$ cm
Thickness	$d = 0.0892$ cm
Cross section	$q = \pi d^2/4 = 0.00622$ cm²
Density	$\varrho = 18.6$ g/cm³
Mass	$m = \pi d^2 l \varrho/4 = 1.24$ g
Modulus of elasticity	$E = 2.83 \cdot 10^{12}$ dynes/cm²
Equatorial moment of inertia	$I = \pi d^4/64 = 3.11 \cdot 10^{-6}$ cm⁴
Separation of the wires	$r = 0.617$ cm

average load acts upon it of $l \cdot p_0$ = about 100 g, *i.e.* 80 times its own weight.

In order to obtain an idea about the bending of the wire in a simple way let us consider it as a rod, which is supported at both ends. Furthermore we assume that the rod has the same elastic properties throughout its whole length [1]). For such an elastic system the frequencies at which it will come into resonance can be calculated according to the formula

$$f_n = \frac{(2n+1)^2\pi}{2\ l^2}\sqrt{\frac{EI}{\varrho q}}, \text{ with } n = 0,1,2, \ldots \quad (6)$$

The length of the rod l occurring herein, the modulus of elasticity E, the equatorial moment of inertia I of the cross section of the wire, the density ϱ and the cross section q (all at the working temperature) can be taken from table I. One then finds:

$$f_0 = 121 \text{ c/s},$$
$$f_1 = 1\,085 \text{ c/s},$$
$$f_2 = 3\,020 \text{ c/s, etc.}$$

None of these frequencies lies in the immediate neighbourhood of the frequency of the varying force component (1 280 c/s). Resonance phenomena need not therefore be expected, and the order of magnitude of the result will not be affected if for the sake of simplification we entirely neglect the varying term of the force (4). Furthermore it may be seen that the rod vibrating at its fundamental frequency f_0 has already completed almost two full cycles before the force has fallen to one half. In calculating the maximum deviation therefore no large error will be made if the picture is further simplified by also neglecting the damping of the force [2]).

The problem is now reduced to the case represented in *fig. 5:* a uniformly distributed load of the magnitude p_0 (equation (5)) is applied at the moment $t = 0$ to a homogeneous rod supported at both ends.

Such a suddenly applied load always causes a greater deviation than the same load in the equilibrium condition (static load). In oscillation systems with a single degree of freedom, for example, it is known that this makes a difference of a factor 2. We shall therefore find a lower limit for the expected deviation of the rod if we simply as-

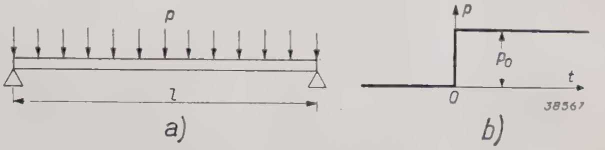


Fig. 5. The filament is considered as a homogeneous rod supported at the ends, on which acts a uniformly distributed load p (a) of the character shown in (b).

sume a static load of the magnitude p_0. The following formula is then valid for the greatest deviation δ occurring at the middle of the rod:

$$\delta = \frac{5}{384} \cdot \frac{p_0 l^4}{EI} \quad \ldots \ldots \quad (7)$$

With the data of table I it follows from this that

$$\underline{\delta = 0.183 \text{ cm}} \quad \ldots \ldots \quad (8)$$

If we now calculate the maximum tensile stress δ occurring at the middle of the rod, for which in the case of fig. 5a the following formula is valid:

$$\sigma = 4.8 \frac{Ed}{l^2} \delta \text{ dynes/cm}^2,$$

we find a value of about 2 000 kg/cm². Since the tensile strength of tungsten at the working temperature of 2 500 °K is only 470 kg/cm² [3]) the material will begin to yield long before the deviation given by (8) has been reached. The wires will therefore either break or undergo permanent deformations which may be considerably greater than the bend according to (8). Since already at $\delta = (r-d)/2 = 0.265$ cm there is contact between the two wires which attract each other, it is of little use to give a more exact calculation for the rough estimation here given [4]). For a slightly different situation, however, a more exact calculation will be given below.

[1]) The first assumption is not entirely correct, since the filament is clamped at one end, while at the other end the fastening is intermediate between clamping and supporting. At the latter point the wire passes by means of a kink over into the adjacent wire. This kink is kept in place by a hook. The second assumption, that of homogeneity of the rod, is also not entirely correct, since the temperature of the filament is somewhat lower at its ends due to heat conduction from the supply terminal and hook, so that the modulus of elasticity is higher than in the middle.

[2]) A more exact calculation in which the damping was not neglected gave as a result that the maximum deviation already occurs after 0.004 sec, *i.e.* after even less than half a period of the fundamental vibration.

[3]) According to W. Espe and M. Knoll, Werkstoffkunde der Hochvakuumtechnik, J. Springer, Berlin 1936, fig. 15.

[4]) It must be pointed out that the various simplifications which are introduced have mutually opposite effects: the damping of the force, the fact that the current may only flow through a part of the wire, that the wire is more or less clamped and is somewhat stiffer at its ends due to the lower temperature, all these facts make the deviation smaller. That the loading is not static, but suddenly applied, makes the deviation greater, in the same way the varying force component contributes to this. All in all it is fairly certain that the region of yield will be reached, and this is already sufficient for the train of thought here followed.

Experiments

While the calculation given above already makes it clear that the damage observed due to the Rocky Point effect can indeed be explained by the simple mechanism proposed, it nevertheless still seemed desirable to obtain a graphic confirmation of this by imitating the effect experimentally. For this purpose the same type of filament as in the example considered was mounted in a glass bulb, while with the connections represented in *fig. 6* a condenser of 540 μF which was changed to 1 000 volts could be discharged via the two parallel branches of the filament. Here also a clearly visible permanent bend in the wires occurred upon discharge. By repeating the discharging of the condenser several times the bend could be made greater and greater, as may be seen in the photographs of *fig. 7a-d*. If afterwards the direction of the discharge current in one of the two branches of the filament was reversed (the two branches had separate leads out of the bulb for this purpose, see *fig. 8*), the wires which then repel each other could be forced apart again to the original condition by a number of discharge impulses.

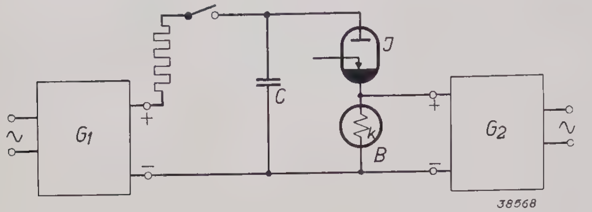


Fig. 6. Connections for the experiments with a model. The filaments k are placed in a bulb B. The condenser C is charged to 1 000 volts by the rectifier G_1, and can be discharged *via* the relay valve J and the filaments k. The relay valve, a glass vessel with a carbon anode, an auxiliary electrode and a pool of mercury as cathode, flashes over when an impulse voltage is applied to the auxiliary electrode; it serves here as a switch for the very high currents. By means of the rectifier G_2 the filaments are heated in order better to imitate the working conditions (smaller modulus of elasticity, lower yield value).

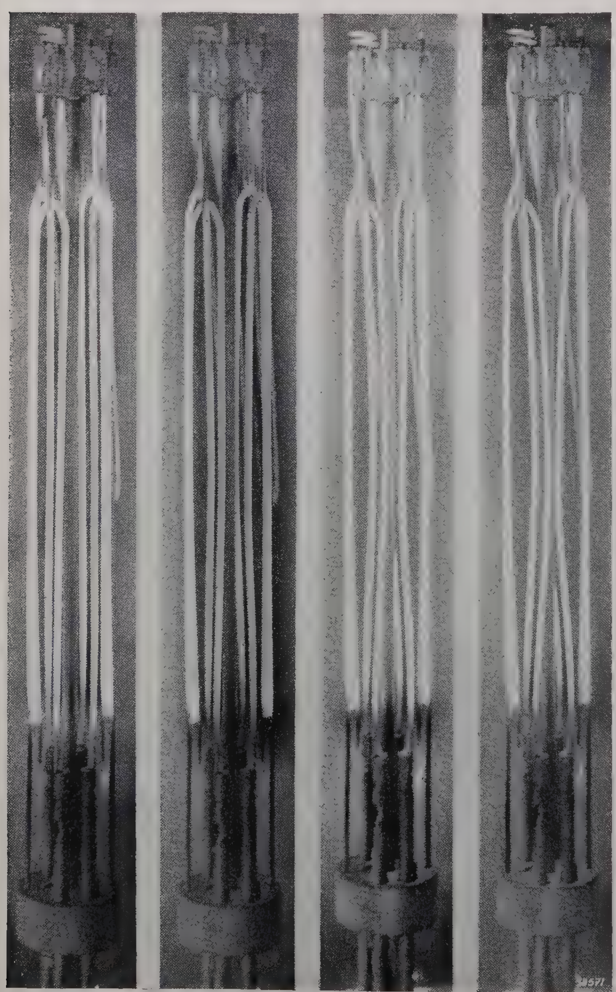


Fig. 7. After a number of discharge impulses a clearly visible permanent deformation of the filaments had occurred: *a*) initial condition, *b*) after 6 discharges, *c* after 12 discharges, *d*) after 18 discharges.

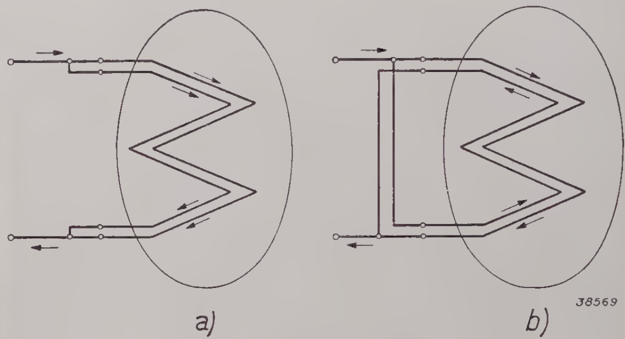


Fig. 8. The two branches of the cathode are led out of the bulb separately, in order to be able to send the discharge currents through the adjacent wires in the same direction (*a*) as well as in opposite directions (*b*).

In these experiments, where the mechanism which was assumed as an explanatory one is as it were isolated, and other phenomena which might play a part in the complex structure of a transmitter valve are excluded, the typical deformations of the Rocky Point effect actually do occur.

Combatting the damage

The obvious question now is what must be done to avoid the defects described? As long as it is impossible to attack the evil at its root (the spontaneous freeing of a small amount of gas) attempts must be made at least to eliminate the harmful effects of the discharge. This can be done very simply by including in the supply line of the anode a resistance of adequate size. This resistance is connected directly in series with the choking coil L (see fig. 1).

If in this way the total resistance of the discharge circuit is made 40 ohms, for instance, then in formula (2) the "angular frequency" β becomes

imaginary, namely $\beta = j \cdot 3\,200$. The discharge is therefore no longer oscillating but aperiodic. Equation (1) now becomes

$$i = i_m' \left[e^{-(a-\gamma)t} - e^{-(a+\gamma)t}\right], \quad . \quad . \quad (9)$$

with $\gamma = \beta/j = 3\,200\ \mathrm{sec}^{-1}$, $i_m' = \dfrac{V}{2\ L\gamma} = 960$ A,

$$a = \frac{R}{2\ L} = 5\,100\ \mathrm{sec}^{-1}.$$

In *fig. 9* this curve is plotted. The peak value of the current, which is reached after about 1/4 000 sec, is in this case also still considerable, namely about 480 A; there is, however, a very much greater damping than in the above discussed case where $R = 0.1$ ohm: the current has practically disappeared after 0.002 sec. For the force which acts per cm length of the filaments we find with (3) and (9):

$$p = \frac{i_m'^{\,2}}{200\,r} \left[e^{-2(a-\gamma)t} + e^{-2(a+\gamma)t} - 2e^{-2at}\right]. \quad (10)$$

This is a similar curve to that in fig. 9 with a still greater damping. Thus in this case a force is exerted on the eleastic rods for only a very short time, and consequently only relatively small deviations will occur.

Since the loading now no longer resembles the static case in the least, the calculation of the deviations should be carried out by means of the differential equation of the vibrating rod. This calculation is sketched briefly at the end of the article. We may however, also obtain a good idea of the expected deviation again by a rough estimation.

Due to the fact that the force acts for such a short

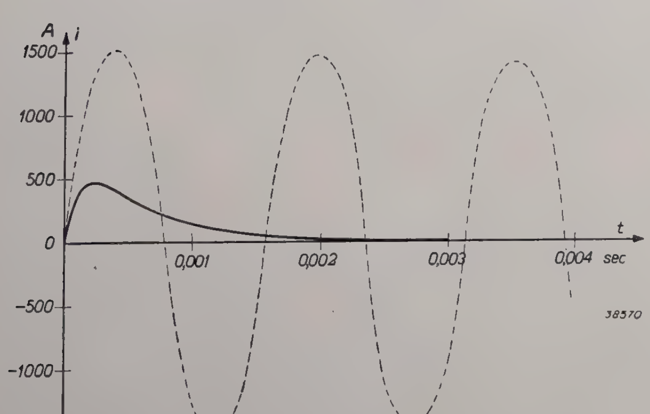


Fig. 9. Behaviour of the current i with a discharge similar to that in fig. 3, but with a resistance of 20 ohms in place of that of 0.1 ohm. The discharge is now aperiodic and practically dies out after 0.002 sec. The scale of the abscissa is 10 times that used in fig. 3 For the sake of comparison the behaviour of the current in fig. 3 is indicated by a broken line.

time we may assume that the whole impulse $P = \int pl\, dt$ is applied to the rod while it is still at rest. All the particles of the rod then take on a certain initial velocity v and the rod therefore receives a kinetic energy $K = \int {}^1\!/_2\, v^2\, dm$. If we assume that all the particles of the rod move in phase (fundamental vibration of the rod), the rod will have reached its greatest deviation only after a quarter period of the vibration, the kinetic energy is at that moment entirely converted into work of deformation U. If the shape of the rod in vibration corresponds to that upon static bending — an assumption which will certainly not be far from the truth —, there is the following relation between the work of deformation U and the deviation δ at the middle:

$$\delta = \frac{5}{384} \sqrt{\frac{240\ l^3}{E\ I}\, U} \quad . \ . \ . \ . \ . \ . \quad (11)$$

We may therefore calculate δ directly from (11) if we know the relation between the initial value K $(=U)$ of the kinetic energy and the impulse P applied. To find this we consider that the initial velocity v at the ends of the rod will be zero and at the middle a maximum (vmA). If we assume that at the middle the impulse is completely converted into movement then the following is valid (m is the total mass of the rod):

$$\frac{m}{l}\, v_{\max} = \int p\ dt = \frac{P}{l},$$

and with a sinusoidal distribution of the initial velocity (corresponding to a sinusoidal form of the bent rod) the kinetic energy becomes

$$K = \int_0^l \frac{1}{2} \frac{m}{l} \left(v_{\max} \sin \frac{\pi x}{l}\right)^2 dx = \frac{m}{4}\, v^2_{\max},$$

thus $K = \dfrac{1}{4m} P^2$.

The impulse $P = \int pldt$ may be calculated from equation (10), where for the sake of simplicity one may integrate from zero to infinity, since the "tail" of the force curve does not furnish any appreciable contribution. The result of the integration is:

$$P = 10.0 \text{ dyne sec.}$$

Thus $U = K = 20.2$ ergs

and according to (11): $\delta = 0.0105$ cms.

A more exact calculation gives a value which agrees very well with this ($\delta = 0.0117$ cms, see below).

The deviation of the wires is thus reduced to a

fraction of the original value (equation (8)) by the connection of the resistance of 20 ohms in the anode connections. The highest tensile stress in the wire becomes only about 100 kg/cm^2 in this case and no permanent deformations result.

Appendix: Exact calculation of the deviation

If x is the coordinate along the rod, u the transverse deviation which depends upon x and the time t, the following differential equation holds:

$$\frac{\partial^2 u}{\partial t^2} + c^2 \frac{\partial^4 u}{\partial x^4} = \frac{p(x,t)}{\varrho q}, \quad \ldots \ldots \quad (12)$$

where $$c^2 = \frac{EI}{\varrho q}$$

and where the initial conditions are

$$u(x,0) = 0 \text{ and } \left(\frac{\partial u}{\partial t}\right)_{t=0} = 0.$$

In our case, where the force p depends only on t and not on x, the solution of the differential equation may be written in the form [5])

$$u(x,t) = \sum_{n=0}^{\infty} f_n(x) \varphi_n(t). \quad \ldots \ldots \quad (13)$$

[5]) The general solution which also holds for the case where p depends upon x is found in H. Schmidt, Zur Theorie der erzwungenen Transversalschwingungen homogener Stäbe konstanten Querschnitts, Z. Phys. **64**, 411, 1930.

The total vibration form is here built up of the so-called natural vibration forms

$$f_n(x) = \sin \frac{(2n+1)\pi x}{l}, \quad \ldots \ldots \quad (14)$$

each multiplied by a certain time function:

$$\varphi_n(t) = \frac{4l^2}{\pi^3 \varrho q c} \frac{1}{(2n+1)^3} \int_0^t p(s) \sin \frac{(2n+1)^2 \pi^2 c (t-s)}{l^2} \mathrm{d}s. \quad (15)$$

In (15) the factor $1/(2n+1)^3$ occurs which decreases rapidly with increasing n, in addition to which the integration also gives a factor of the order of $1/(2n+1)^2$. We may therefore neglect the contribution of the higher natural vibration forms to the total vibration, i.e. the rod moves practically according to its fundamental vibration ($n = 0$), whereby according to equation (14) it takes on the form of a half sine. The solution (13) now becomes simply

$$u(x,t) = \frac{\sin \pi x}{l} \varphi_0(t),$$

where the time function $\varphi_0(t)$ for our example (with $R = 20$ ohms) can be calculated in an elementary way from (15) when the expression (10) for the force is substituted in it. The maximum deviation δ in which we are interested occurs in the middle of the rod in the fundamental vibration, where $\sin \pi x/l = 1$, so that δ becomes equal to the maximum value of $\varphi_0(t)$. By setting the differential quotient $\mathrm{d}\varphi_0(t)/\mathrm{d}t$ equal to zero it is found that the first maximum occurs at $t = 0.0025$ sec, and that δ then has a value of 0.0117 cm.

A METHOD OF MEASURING IN THE INVESTIGATION OF BICYCLE DYNAMOS

by H. A. E. KEITZ.

621.313.322 : 629.118.3

If we consider an A.C. dynamo with constant magnetic field, connected to an ohmic resistance, and plot the terminals voltage E as a function of the number of revolutions n, we obtain a curve of the type sketched in *fig. 1*. The voltage at first increases proportionally with n and reaches a constant value at higher values of n. The region of the characteristic on which the dynamo will work when in use depends not only upon its construction but also very much upon the resistance to which it is connected.

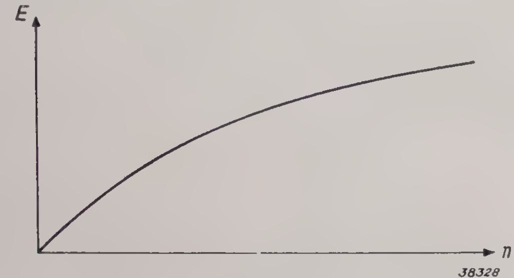


Fig. 1. General form of the variation of the terminals voltage E of an A.C. dynamo loaded with a resistance, as a function of the rate of revolution n.

In the case of bicycle dynamos the aim will be to have the operating point in ordinary use lie on the flat part of the characteristic as far as possible. The rate of revolution in the case of the bicycle dynamo varies very widely, since it is practically proportional to the speed of the bicycle, which may vary for instance from 3 to 20 m.p.h. If the characteristic is not sufficiently flat in the region corresponding to these speeds, it means that the lamp connected to the dynamo is already very much overloaded at speeds slightly higher than the normal, and will therefore quickly succumb, while at speeds slightly less than normal it gives hardly any light.

We shall not at this moment go into the structural measures by which the desired characteristic can be obtained [1]), but shall explain the important influence of the resistance in connection with the shape of the characteristic at normal rates of revolution. This could be demonstrated by plotting the relation between terminals voltage and speed of the bicycle for a number of different resistances. In practice, however, the dynamo is not loaded with a constant resistance, but with a lamp whose resistance varies quite sharply with the temperature of the filament and thus also with the terminals voltage. It is therefore better to study the relation between the terminals voltage and the speed of revolution for a given lamp.

In *fig. 2* this relation is given for the Philips bicycle dynamo, type No. 7 405 in connection with different lamps. It may be seen that with the lamp of 6 V-0.5 A, for which the dynamo is designed, the terminals voltage varies from 3.3 to 7.7 V for the two extreme speeds of the bicycle. With a lamp of 6 V-0.4 A the corresponding variation is from 3.8 to 10.7 V, with a lamp of 6 V-0.6 A it is 2.9 to 5.7 V. The lamp of 6 V-0.4 A, being too small, already reaches its nominal voltage at the low speed of 5 p.m.h., and at higher speeds therefore it will quickly succumb; the too large lamp of 6 V-0.6 A does not burn at the nominal voltage (and with the nominal light flux) even at the highest speeds of 20 p.m.h.

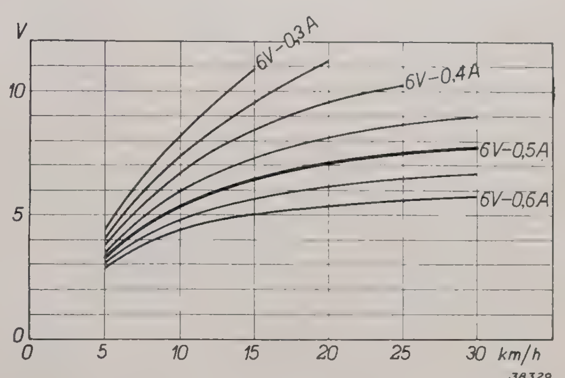


Fig. 2. Terminals voltage of the Philips bicycle dynamo 7 405 as a function of the speed of the bicycle for a load consisting of one of a number of different lamps. The best compromise between length of life and light flux of the lamp is obtained with the characteristic indicated by a thick line.

This shows clearly that dynamo and lamp must be mutually adapted [2]).

The testing of this adaptation amounts to recording the characteristic of the dynamo, preferably under normal conditions of use. Special attention must hereby be paid to two points. The load on the dynamo may not be changed by the connection of the measuring instruments, since the charac-

[1]) See on this subject: H. A. G. Hazeu and M. Kiek, An alternating current dynamo with a flat characteristic for bicycle illumination, Philips techn. Rev. 3, 87, 1938.

[2]) If two lamps in parallel are connected to the dynamo, the total current must have the prescribed value. If for example there is a lamp for 4-6 V-0.04 A in the rear light of the bicycle, a lamp of 6 V-0.45 A must be chosen for the headlight if the same characteristic is to be obtained as for a 6 V-0.5 A lamp alone.

teristic is so very sensitive to such a change, *i.e.* the measurement of the voltage must require practically no energy. Furthermore the A.C. voltage furnished by bicycle dynamos is in general not truly sinusoidal, so that account must be taken of whether or not the voltage measured actually corresponds to the effective value.

A very simple method of measuring, which avoids all difficulties in this respect and which we have now used for some time, is the following. The lamp which represents the load on the bicyle dynamo is connected successively to the dynamo and to an accumulator battery with a variable series resistance. If this resistance is so adjusted that the lamp gives the same light flux in both cases, the voltage on the lamp will then also be the same in both cases. The measurement of the terminals voltage of the dynamo is thus replaced by a simple D.C. voltage measurement which can be carried out with great accuracy. In order to be able to adjust the lamp to equal light flux, it is placed in a photometer sphere, *fig. 3* (instead of a sphere a box of any desired form may be taken) at the measuring window of which a photoelement is placed (a blocking-layer photocell). The photocurrent, which is read off on a milliammeter, is a measure of the light flux.

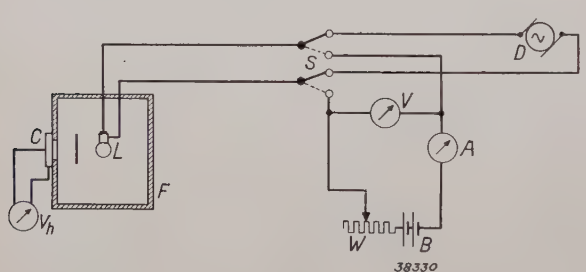


Fig. 3. Arrangement for the recording of dynamo characteristics. The dynamo *D* is driven by a motor with a variable number of revolutions which may be read off with a tachometer. The lamp *L* which is placed in a "photometer sphere" *F* is connected alternately to the dynamo and to an accumulator battery *B* by means of the switch *S*. The series resistance *W* is so adjusted that the lamp gives the same light flux in both cases, which is checked by means of the milliammeter V_h which indicates the photocurrent of the blocking-layer photocell *C*. The lamp voltage measured with the voltmeter *V* is then equal to the effective value of the terminals voltage of the dynamo. If desired, the lamp current can also be controlled with *A*.

The D.C. voltage measured will be equal to the effective value of the A.C. voltage supply, if it is permissible to assume that the light flux of the lamp is determined by this effective value, and no longer depends upon the form of the A.C. voltage. This is indeed the case if the frequency of the A.C. voltage is sufficiently high. Experience shows that even at the ordinary mains frequency of 50 c/s there is no measurable deviation of the light flux compared with that upon supply be means of a D.C. voltage equal to the effective value. Since the frequency of the A.C. voltage furnished by bicycle dynamos is in general considerably higher than 50 c/s — in the case of the Philips dynamo 7 405 it is already 70 c/s at a speed of 3 p.m.h. — the light flux may immediately be used as intermediate in the voltage measurement. Furthermore the requirement that no extra load on the dynamo may result from the measurement is here automatically satisfied.

The accuracy of the method is more than adequate. The voltage measurement for each point of the characteristic to be measured (*i.e.* for each rate of revolution) requires three readings, namely two on the milliammeter for the light flux and one on the voltmeter for the lamp voltage. The readings of the light flux are not, however, critical, since with the lamps used here the light flux varies about 3.5 times as much proportionally as the supply voltage, so that an inaccuracy in the adjustment to equal light flux has only a small effect.

It might be imagined that the comparison of the dynamo with the battery could be made superfluous by calibrating the milliammeter V_h directly in volts for a given lamp. Instead of three readings only one reading would then be necessary. This immediately meets with the objection that the ratio between light flux and voltage of the lamp changes with time: especially upon the recording of measured points in the region of high speeds (high voltages) a relatively rapid blackening of the bulb of the lamp takes place which would cause the calibration to change gradually. In the above-described comparative measurements this of course causes no difficulty if the readings are carried out in quick enough succession.

RESONANCE CIRCUITS FOR VERY HIGH FREQUENCIES

by C. G. A. von LINDERN and G. de VRIES.

538.565

Different concepts connected with the properties of electrical resonance circuits are discussed in this article. In particular the reasons are given why, in radio technology, from a coil and a condenser there has been a development toward cavity resonators, Lecher systems and cavity resonators for higher and higher frequencies.

Introduction

A familiar property of Maxwell's equations may be described in the following way. If all the dimensions of a system (and also the specific resistance ϱ) are reduced n times, the same voltages and currents will occur in this system as in the original one, if the frequency is multiplied by n (the wave length is n times smaller). It might be supposed that this would furnish sufficient guidance for the construction of short wave apparatus, and particularly of resonance circuits for short waves, were it not for the fact that for all kinds of reasons it is often impossible to decrease all the dimensions proportionally. Especially the reduction of the specific resistance in the desired proportion is often impossible since copper is used for the conductors even at low frequencies, and there is no available material which conducts appreciably better. We must therefore devise constructions which exhibit considerably better properties than the coils and condensers ordinarily used at low frequencies. Such constructions do actually exist; they are not, however, used at low frequencies because their dimensions would be too large for that purpose. It is because of the fact that at high frequencies all the components are proportionally smaller that these relatively large dimensions are then no objection. While of course the properties of these circuits also become worse upon reduction in size, due to the fact that the conductivity cannot be increased, nevertheless, because they are so much better than the ordinary ones at low frequencies, they are still just good enough at high frequencies.

We shall attempt to discover the line which has been followed in this development. Before doing so we shall first review briefly a few of the concepts connected with resonance circuits in general.

Resonance width and quality factor

The simple LC circuit with which we begin is represented generally as a connection in series of a resistance r and a self-induction L, in parallel to which is connected a capacity C (*fig. 1*). The total impedance Z of such an oscillating circuit is given by the formula:

$$\frac{1}{Z} = \frac{1}{r + j\omega L} + j\omega C. \quad . \quad . \quad . \quad . \quad (1)$$

By resonance frequency we understand the frequency for which Z is a maximum. With an ohmic

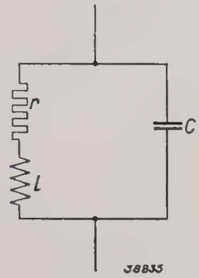


Fig. 1. Simple oscillating circuit consisting of resistance r, self-induction L and capacity C.

resistance r which is small compared with the reactances ωL and $\frac{1}{\omega C}$, the following is approximately valid for this frequency:

$$\omega_0^2 LC = 1. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The total impedance Z of the LC circuit is real upon resonance, and according to (1) and (2) can be represented by

$$R = \frac{L}{Cr} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For an angular frequency which differs by $\Delta\omega/2$ from the resonance frequency, let the impedance have fallen to $R/\sqrt{2}$ (*cf. fig. 2*). For $\Delta\omega$ one then finds

$$\Delta\omega = \frac{r}{L} \text{ if } r \ll \omega L). \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

This quantity $\Delta\omega$ is called the resonance width of the circuit, and the quotient of the angular frequency ω_0 at resonance and this resonance width $\Delta\omega$ is a measure of the sharpness of resonance of the circuit and is called the quality factor Q:

$$Q = \frac{\omega_0}{\Delta\omega} \text{ and with (4), } = \frac{\omega_0 L}{r} \quad . \quad . \quad . \quad (5)$$

The resonance is sharper and the quality factor greater, the smaller the ohmic resistance r and the

greater the self induction L. Under those circumstances a freely oscillating circuit also has the least damping. This realtion between the sharpness of resonance for a forced vibration and the damping of a free vibration will be considered somewhat more closely.

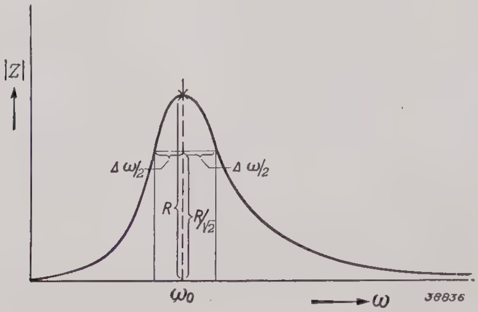


Fig. 2. Variation of the absolute value $|Z|$ of the impedance of a connection in parallel of a capacity C and a self-induction L as a function of the angular frequency ω. At the resonance frequency ω_3 the impedance is practically equal to L/Cr, where r represents the resistance.

Quality factor and damping

The free oscillation in an electric circuit with a characteristic oscillation time T may be written as follows:

$$i = i_1 \sin \frac{2\pi t}{T} = i_0 e^{-\Theta\, t/T} \sin \frac{2\pi t}{T} \quad . \quad . \quad (6)$$

In this expression, if Θ is small enough, i_1 represents the "momentary" amplitude of the slowly decreasing oscillation (*fig. 3*). The quantity Θ is called the logarihmic decrement and represents the natural logarithm of the ratio between two successive amplitudes. With an ohmic resistance r the heat losses during one period T are equal to $^1/_2\, i_1^2\, rT$. The total energy content of the oscillating circuit is $^1/_2\, L\, i_1^2$ and it decreases proportionally with

$$[e^{-\Theta\, t/T}]^2 \approx 1 - \frac{2\,\Theta t}{T}.$$

The decrease per period is thus $\Theta L\, i_1^2$ and this must be equal to the heat $^1/_2\, i_1^2\, r\, T$ developed per period. It therefore follows that the logarithmic decrement

$$\Theta = \frac{rT}{2L} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

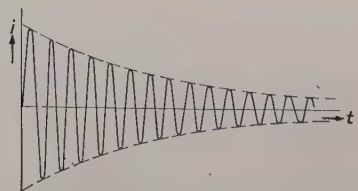


Fig. 3. Damped vibration.

Since $\omega_0 T$ is equal to 2π, the following relation is found between logarithmic decrement and quality factor

$$\Theta = \frac{\pi}{Q} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

If we write formulae (7) and (8) in the form

$$Q = \frac{2\pi}{T} \frac{L i_1^2}{r i_1^2}, \quad . \quad . \quad . \quad . \quad . \quad (9)$$

which is also in accordance with (5), we have obtained Q in a form which is also significant when we are no longer concerned with a simple LC circuit. Equation (9) is then read as follows:

$$Q = 2\pi \cdot \frac{\text{field energy}}{\text{energy dissipated per period}}; \quad (9a)$$

in many cases for more complicated systems (the cavity resonators, resonating cavities and Lecher systems to be described) it can be proved that equations (8) and (9a) are also valid.

An exception is formed by band-pass filters for example. Under certain circumstances there may be several resonance frequencies, two or more of these frequencies may not, however, lie too close to each other, as is the case in the band-pass filter which is used in the intermediate-frequency amplifiers of a radio receiving set.

Skin effect

For the resistance r occurring in the formulae we must not use the ordinary D.C. resistance but the A.C. resistance which is so much higher due to the well known skin effect. We shall not here go into the theory of the skin effect, but shall only recall a few main features of it [1]). At very high frequencies, no magnetic field — or strictly speaking only a very weak one — will be found in the interior of a good conductor. This is understandable when it is kept in mind that due to the high frequency the result of a magnetic alternating field would be that high voltages would be induced in the conductor, which would lead to strong eddy currents of such a sort that they would cause in turn a magnetic field which is oppositely directed to the original field. In a straight wire of circular cross section at very high frequencies the current flows in a thin layer on the outside of the wire. The fact that this situation satisfies the requirement of producing

[1]) The phenomenon of skin effect should not be conceived as if the currents repelled each other because:
1. conductors through which currents flow in the same direction do not repel but attract each other,
2. the forces act between the conductors and not between the currents as such,
3. there is no skin effect for direct current.

no magnetic field in the interior is due to the fact that a cylindrical ring of uniformly distributed current lines of force causes a magnetic field toward the outside, but none toward the inside (*fig. 4*).

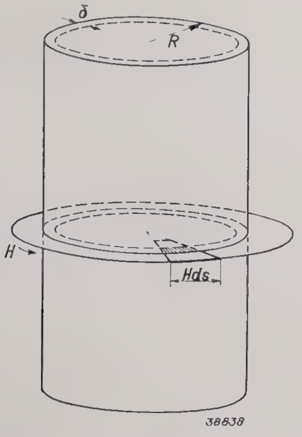


Fig. 4. Diagrammatic representation of a straight conductor of circular cross section in which skin effect occurs, so that the current flows chiefly in the layer δ.

The line integral of the magnetric force $2\pi RH$, which must be proportional to the "enclosed" current, will be zero when we choose our radius smaller than that of the current lines cylinder, since no current is enclosed on the inside.

The result of the skin effect is that only a part of the cross section of the conductor is used for the current, which amounts to an apparent increase in the resistance. The current density in the current carrying layer decreases from the outside inwards as $e^{-x/\delta}$, where x represents the depth below the surface of the conductor (*fig. 5*). In the case of a wire of circular cross section, this is therefore in the direction of the radius. δ is called the **depth of penetration**. The current becomes very small in the interior of the conductor, but not exactly zero, in accordance with the e power. It may still be asked how thick the wall of a hollow conductor must be to develop the same amount of heat as the solid conductor with a given total current in both

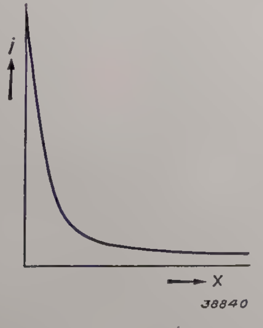


Fig. 5. Current distribution over the cross section of an electric conductor due to the skin effect. The current density i varies approximately exponentially with the distance x to the surface of the conductor.

cases. This might be called the equivalent thickness. It is then found that the equivalent thickness is equal to the depth of penetration [2]).

For δ is found:

$$\delta = c_1 \sqrt{\varrho \lambda},$$

where ϱ is the specific resistance and λ the wave length. The fact that the layer is thicker with higher specific resistance is also quite easily understandable: the mechanism which keeps the interior of the conductor free of field acts less perfectly in a poor conductor than in a very good conductor, due to the ohmic losses. For copper the depth of penetration becomes:

$$\delta_{\mathrm{cm}} = 4 \cdot 10^{-5} \sqrt{\lambda_{\mathrm{cm}}} \quad \ldots \quad (10)$$

For the resistance of a conductor of circular cross section one finds:

$$r_{\mathrm{w}} = \varrho \frac{l}{2\pi R\delta} \quad \ldots \ldots \quad (11)$$

instead of, as in the D.C. case:

$$r_0 = \varrho \frac{l}{\pi R^2} \quad \ldots \ldots \quad (12)$$

Furthermore for a flat strip (see *fig. 6*):

$$r_{\mathrm{w}} = \varrho \frac{l}{2(b+a)\delta} \quad \ldots \quad (13)$$

If the frequency is not too high, so that the current is no longer concentrated in a very thin layer, the

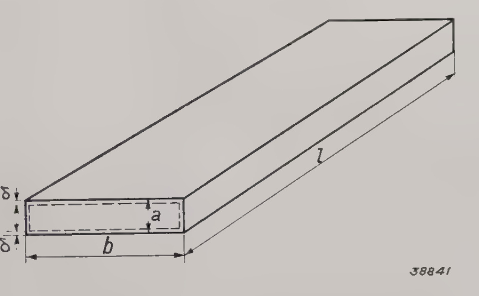


Fig. 6. Conducting wide strip of a length l, a width b and a thickness a. The depth of penetration for a high-frequency alternating current amounts to δ because of the skin effect.

formulae are much more complicated [3]) than the simple exponential law mentioned above. Such cases are, however, of no importance for our subject, resonance circuits for very high frequencies.

If there is more than one straight conductor,

[2]) In the derivation the phase shifts occurring in the layer must be taken into account.

[3]) See: H. G. Möller, Grundlagen und mathematische Hilfsmittel der Hochfrequenztechnik (Springer, Berlin 1940), who on page 34 also begins with a coil of wide strip and considers particularly the lower frrquencies.

or if for other reasons a magnetic A.C. field is already present, the current density is not the same at every spot on the surface of the conductor, but a current distribution occurs such that the field in the interior of the conductor is again very small. In order to ascertain on which side of the surface of the conductor the most current will be encountered, use may be made of the fact that the current on the surface is greatest where the magnetic field is greatest.

Since the magnetic field within the current layer is negligibly small, the line integral in fig. 4 is equal to $H ds$ (the two sides are perpendicular to H and thus do not contribute to the line integral); the current enclosed becomes $i_1 ds$ when there is a current i_1 per centimetre circumference of the layer, so that H is proportional to i_1. This rule is only useful in cases where the skin effect occurring does not alter the shape of the magnetic field outside the conductor too much, but such cases frequently occur.

Thus in the case of a cylindrical coil the greatest current density will be found at the inside of the coil where the magnetic field is strongest (*fig. 7*). Practically no current flows on the outside in the case of long coils.

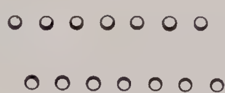


Fig. 7. Diagram of the current distribution in the wires of a cylindrical coil as a result of the skin effect.

On the basis of a consideration of the coil made of wide strip — which somewhat unusual type of coil is chosen because of the simplicity of the calculations — and the torus, we shall now attempt to explain why high-frequency technique, beginning with the ordinary coil has developed in the direction of the cavity resonator, Lecher system and cell-resonator which are always more important on short waves.

The long coil made of wide strip

In a long straight conductor (fig. 6) with a length l, a width b and a thickness a which is small compared with b, a current of sufficiently high frequency flows mainly through a surface layer of the thickness δ due to the skin effect just discussed, so that the resistance is

$$r_w = \varrho \frac{l}{2b\delta} \quad \ldots \ldots \quad (14)$$

This long wide strip is now bent to form a coil of one turn (*fig. 8*), forming thus a cylinder with a thickness a, a circumference $l = 2\pi R$, when R represents the radius, and a length b. The result is that current now flows only on the inside of the cylinder (with the depth of penetration δ), as indicated in fig. 8, so that the resistance of such a

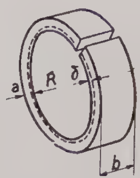


Fig. 8. The length of wide strip of fig. 6 is bent to one winding with a circumference $l = 2\pi R$, a width b and a thickness a. As a result of the skin effect high-frequency alternating currents now flow only through a layer δ lying on the inside of the winding.

coil of wide strip for sufficiently high frequencies is twice as great as the A.C. resistance for the straight wide strip of which the coil is made. The A.C. resistance for the strip bent to a coil of one winding is therefore

$$r_w = \varrho \frac{l}{b\delta} = \varrho \frac{2\pi R}{b\delta} \quad \ldots \quad (15)$$

If the strip is wound to a coil of n turns (*fig. 9*) the same considerations are valid, and the A.C. resistance becomes:

$$r_w = \varrho \frac{2\pi R}{b\delta} n. \quad \ldots \ldots \quad (16)$$

The self-induction, when the coil is long enough with respect to its width, is:

$$L = 4\pi^2 R^2 \frac{n}{b} \cdot 10^{-9} \text{ henrys.} \quad \ldots \quad (17)$$

From formulae (16) and (17) for resistance and self induction of a long coil of wide strip, its quality factor follows directly:

$$Q = \frac{\omega_0 L}{r_w} = 2\pi R \frac{\omega_0 \delta}{\varrho} \cdot 10^{-9} \quad \ldots \quad (18)$$

Since δ is proportional to $\sqrt{\delta/\omega_0}$ the quality of the coil is inversely proportional to $\sqrt{\varrho}$ and directly proportional to $\sqrt{\omega_0}$. The latter fact seems to offer hope for the high frequencies, but this is not the case. It means that for a given coil the quality be-

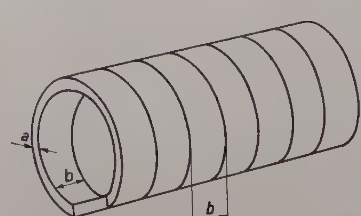


Fig. 9. Straight coil of wide strip, consisting of n windings with a radius R, a width b and a thickness a.

comes better at high frequencies — thus smaller tuning capacity — but the difficulty is that for all kinds of reasons it is often impossible to go lower than a certain tuning capacity so that smaller self inductions are arrived at. This means according to (7) a decrease of the radius R with increasing frequency, whereby according to (18) the quality factor becomes poorer. This effect dominates over the increase in Q with $\sqrt{\omega_0}$ just discussed, so that Q actually decreases with increasing frequency.

In order to allow the radius R to remain as large as possible at high frequency (small self-induction), it is advisable to use a coil with relatively few wide windings. A new source of losses then occurs, however: the coil begins to resemble a loop aerial more and more and will give off energy by radiation, which decreases the value of Q in exactly the same way as the ohmic losses. The torus coil — which we here include in the discussion exclusively as a transition to the cavity resonator meets this objection, and is sometimes actually employed for this reason.

Strictly speaking, it is not usually a question of radiation of tuned circuits, but of induction in more or less poor conductors in the neighbourhood. Another way besides the one here described of decreasing these losses consists in placing the coil in a box of conducting material.

The torus coil

The torus coil is formed from the ordinary cylindrical coil by bending it into a circular ring (*fig. 10*), so that the magnetic lines of force are continuous inside the coil. As a result of this the formulae (16), (17) and (18), which were derived neglecting the radiation losses for the long straight coil, are exactly valid for this case. In order to obtain a good Q even at high frequencies in spite of the small self-induction, we may therefore make the windings large but small in number, without introducing appreciably large extra losses. Proceeding in this way, fewer and fewer windings are used at higher frequencies, until finally only one remains

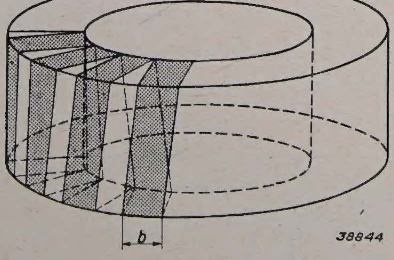


Fig. 10. Rectangularly wound torus coil of wide strip, consisting of a large number of windings of width b, within which the magnetic field is enclosed.

which is just as wide as the circumference of the torus (*fig. 11*). We then have a torus surface which is cut open along a circle in its upper surface.

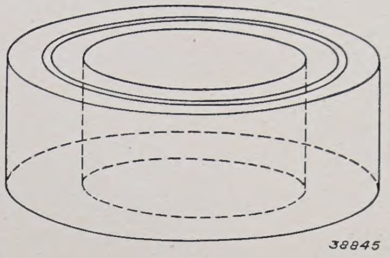


Fig. 11. Rectangularly wound torus coil of one winding with a width equal to the entire circumference of the torus. The coil is cut open on its upper surface along a circular line.

The special form of self-induction L must now be completed with a capacity to form a high-frequency oscillating circuit. If we do this in the manner represented diagrammatically in *fig. 12*, we have derived the so-called cavity resonator from the torus coil.

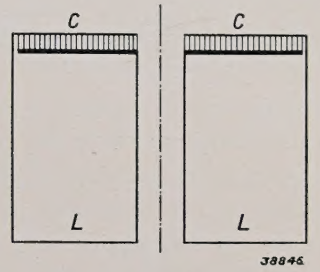


Fig. 12. Cavity resonator in which the concentrated capacity C is introduced against the cover of the resonantor, while the self induction L is furnished mainly by the two concentric cylinders which are joined by the bottom of the resonator.

Cavity resonator

In the case of the cavity resonator in fig. 12 the capacity C is placed against the cover of the resonator. The high-frequency alternating currents to and from the condenser plates flow through the axis, the bottom and the inside of the outer wall. The electrical and magnetic fields are both therefore inside the resonator.

It may in general be said of the quality factor of such a circuit that it is proportional to the quotient of volume and surface of the resonator. Although the cavity resonator is not large compared with the wave length, this is entirely analogous to Sabine's law about the reverberation time in a room. This reverberation time in a room which is large compared with the wave length of the sound is proportional to the quotient of the volume and the sound absorbing surface. The reverberation time is the damping time and therefore inversely proportional to the logarithmic decrement, *i.e.* pro-

portional to the quality factor Q according to formula (8). Formula (18) for the quality factor of a torus coil is in complete agreement with this general statement, because according to that formula Q is proportional to the radius R of the torus. *i.e.* to the quotient of volume and surface.

Meanwhile it must be kept in mind that this statement only forms a guide and must be used with care. The proportionality factor also contains certain other quantities which take into account the shape of the space, especially when it is small with respect to the wave length. It therefore serves no useful purpose to increase the volume by making the core thinner, on the contrary, the higher ohmic resistances which will thereby be caused will quickly make the value of Q considerably worse. It can, however, be said that long thin resonator models are poorer than more or less "square" ones, since the latter have a much more favourable relation between volume and surface [4]).

In order to reach a high impedance it is of still greater importance than for attaining very good quality to make the self-induction large, since $Q = \omega L/r$ and $R = L/Cr = \omega^2L^2/r$. This is why in cases where one is not bound for some reason or other to a minimum capacity, the condenser of the cavity resonator must be made as small as possible. The introduction of a specially concentrated capacity as in fig. 12 will then finally be omitted, and only a more or less shortened core is retained. If its length is fairly large compared with the diameter of the resonator the system becomes that of two concentric conductors, which is usually called a concentric Lecher system, *fig. 13.* The dimensions of our "circuit" are now no longer small compared with the wave length, on the contrary, the resonance wave length is found to be only about four times as great as the length of the "core" in fig. 13, as follows from the theory of Lecher systems, to which we shall return in a coming number of this periodical.

The attempt to increase still further the ratio between volume and surface leads to increasing the diameter of the concentric Lecher system. The relative thinness of the core, however, stands in the way of any considerable improvement in Q due to its high ohmic losses.

It is found that when we have increased the diameter of the resonator until it has the same order of magnitude as the wave length, we then still find resonances when the core has entirely disappeared. Such a system is called a resonance cavity (*cf. fig. 14*).

We have then, however, adopted a whole new group of concepts in our considerations. From the moment when we decrease the capacity of the cavity resonator and therby increase the self-induction so much that all the dimensions are no longer small with respect to the wave length, the phenomena are no longer quasi-stationary.

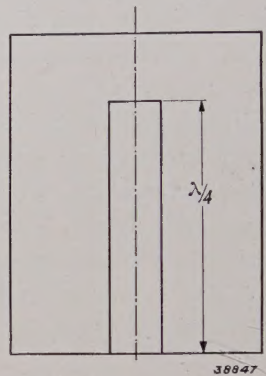


Fig. 13. Concentric Lecher system consisting of a closed metal cylinder with an empty core projecting inwards. The system resonates for a wave length λ which is about four times the length of the core.

Quasi-stationary and non-quasi-stationary

Stationary, quasi-stationary and non-quasi-stationary phenomena may be distinguished. Stationary phenomena are spoken of in the case of systems which are at rest (electrically and magnetically). They are still considered to be at rest when a direct current flows. In this case concepts occur such as resistance, capacity and self-induction, which are defined perfectly unambiguously, and the current in a satisfactorily insulated conductor is the same at all points. In quasi-stationary phenomena the state of rest is disturbed; the currents and voltages are not the same at each moment. The current in a conductor is indeed still the same through its whole length, and as long as all changes take place slowly enough, concepts such as capacity self-induction and resistance retain their significance. In the equations which describe the phenomena which take place in this region, total differentiations with respect to time occur.

What must be understood by "slowly enough" becomes clear upon studying the phenomena which are indicated as non-quasi-stationary. The so-called displacement current which leaves the conductors laterally now begins to play a part, so that the current through the conductor is no longer the same at all points. The equations begin to contain

4) If one studies in detail what is the best model one does not find that the diameter should be exactly equal to the length, but neither does one arrive at very long or flat models.

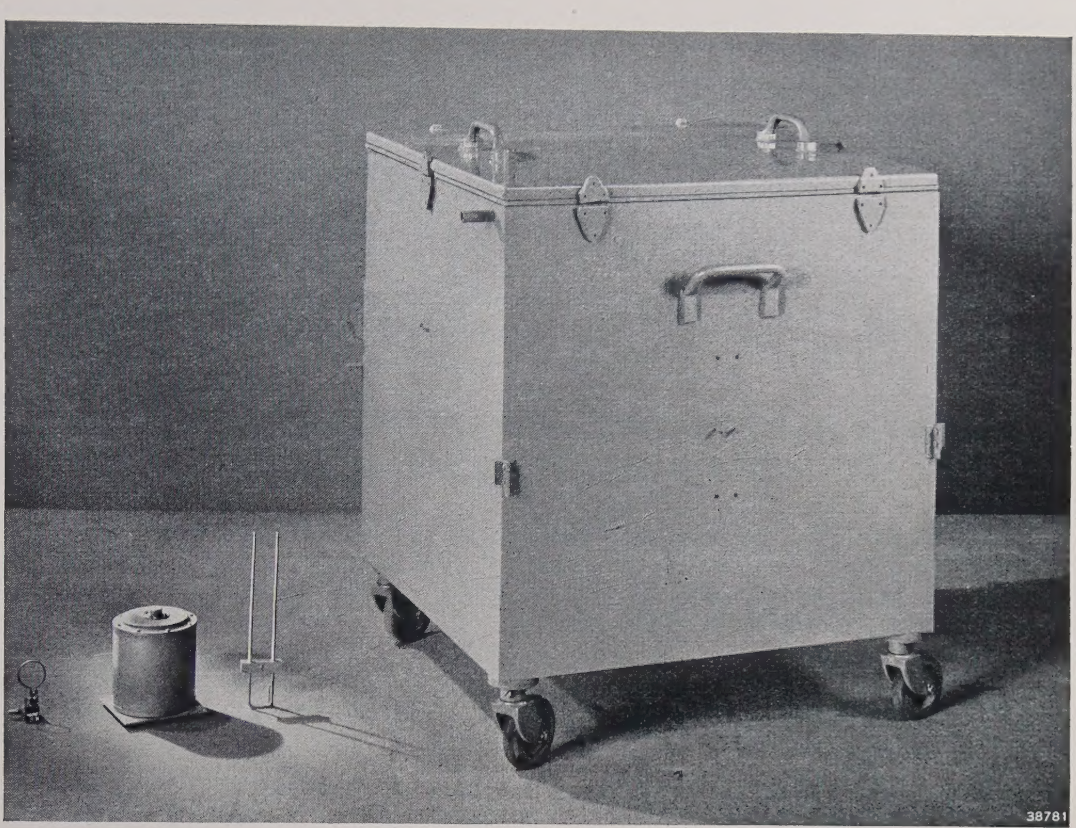


Fig. 14. An *L.C.* circuit, cavity resonator, Lecher system and resonance cavity, all of which are tuned to a wave length of about 1 m, are shown side by side for comparison of their dimensions in this photograph. In the middle of the front wall of the resonance cavity may be seen the connecting wires for the loop situated inside the cavity for the purpose of bringing it into resonance.

partial differentiations with respect to time, their solutions take on a wave character, and we are now also able to define more sharply the "slowly enough" of the foregoing paragraph. When the dimensions are no longer small with respect to the wave length the phenomena are no longer quasi-stationary. In cases in which one dimension is of the order of the wave length, while the others are much smaller, one might speak of semi-quasi-stationary. The Lecher system is an example of this.

In "semi-quasi-stationary" systems a certain significance may still be ascribed to the concepts capacity and self-induction, if they are considered for not too long sections of the system at once. In the entirely non-quasi-stationary systems, to which belong resonance cavities, there can be no question of this.

For the sake of completeness it must be noted that the criterion "large compared with the wave length in a vacuum" is not decisive in all cases. The skin effect for example, where the density and phase of the current depend closely upon position, is a non-quasi-stationary phenomenon, in spite of the fact that it takes place in a layer which is very much thinner than the wave length.

Lecher systems

In our survey of the different types of resonance circuits which are used in short wave technique we have encountered the concentric Lecher system but not the ordinary Lecher system. This is because we were chiefly concerned with the problem of keeping the value of Q satisfactory while passing to shorter and shorter wave lengths. In the meantime there are many cases where it is more a question of the impedance Z. This quantity, $Z_{\max} = L/Cr = \omega^2L^2/r$ may still be very satisfactory while $Q = \omega L/r$ is only moderately good, at least when L is large enough, which means that C should be able to be made small enough. In that case it is advantageous to use the ordinary Lecher system, which consists of two parallel conductors with a short-circuiting shunt which may be moved back and forth along the conductors. Although the Lecher system is not a quasi-stationary system, and one may not therefore speak of self-induction and capacity without some reservation, it is nevertheless clear that the system contains relatively little "capacity", and due to the fact that currents flow in opposite directions through the adjacent con-

ductors, the radiation remains quite small without further shielding, so that the loss resistance does not become too high. The fact that the Lecher system has found such extensive application is due not only to the high value of Z_{max}, but also to the fact that resonance occurs when the length of the system is a whole number of quarter wave lengths, so that it can be used as a wave meter in a very simple way. We shall devote a subsequent article to the properties of the Lecher system, and shall therefore not go more deeply into the question here.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on applications to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabriken, Eindhoven (Holland), Kastanjelaan.

1535: W. Nijenhuis and F. L. Stumpers: On some properties of electrical networks (Physica **8**, 289, Feb. 1941).

The relation between the real or imaginary part of an impedance function and the function itself is derived, with special attention to transmitted impedances. As a result of these considerations two special types of electrical connections can be distinguished, namely those in which the modulus and those in which the phase of the impedance does not depend upon the frequency. The practical construction of such networks is discussed in the article. In conclusion several general properties are discussed of the variation of the phase with frequency.

1536: J. van Niekerk and M. S. C. Bliek: Het genezende effect van groote doses bestraald provitamine D van dierlijken oorsprong éénmaal, oraal of intramusculair, toegediend bij rachitis. (The curative effect of large single doses of irradiated provitamin D of animal origin, administered orally or intramuscularly, in the case of rickets). (Ned. T. Geneesk., **85**, 860-867, Mar. 1941).

As a continuation of the experiments described in **1532**, it is now shown that by administering a single large dose of vitamin D of animal origin to chicks orally or injecting it into a muscle, rickets can be cured. With the amounts used in these experiments no noticeable difference in action could be observed for the different methods of administration of the vitamin. The duration of the cure does not seem to depend upon the quantity used in nor upon the manner of administration. For insuring further normal calcification of the new bone tissue these conditions are, however, of importance. If the vitamin D is injected into a muscle a much smaller dose is sufficient when it is a question of preventing rachitic lesions after the cure is completed. If it is a question of curing rickets with a single dose of vitamin D, therefore, it is advisable to inject it into a muscle.

Contents of Philips Transmitting News **8**, No. 1, March 1941.

H. B. R. Boosman and R. P. Wirix, Transmitter and receiver tuning components.

5 kW tropic proof shortwave broadcast transmitter.

Tj. Douma, Resonance of circuits and lines.